

**THE INCIDENCE OF MAJOR
LEPIDOPTERAN PESTS ON CABBAGE
AND THEIR ASSOCIATED PARASITIDS
IN GHANA**



By

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**THE INCIDENCE OF MAJOR LEPIDOPTERAN PESTS
ON CABBAGE AND THEIR ASSOCIATED
PARASITIDS IN GHANA**

This Thesis is Submitted to the University of Ghana, Legon,
in Fulfillment of the Requirements for the Award of
Doctor of Philosophy (Ph. D.) Zoology Degree.

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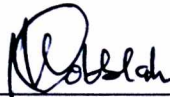
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DECLARATION

I hereby declare that the work herein submitted as a thesis for the Doctor of Philosophy Degree in Zoology (Entomology) is the result of my own investigations and has not been submitted for a similar degree in any other University.



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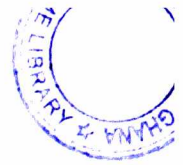
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DEDICATION

To my daughter Amanda Aku Ahornam Awadey who I left several times as a little girl to carry out this work and to my family who took care of Amanda when I had to travel.

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ABSTRACT

The study was carried out at the Weija Irrigation Company site at Tubaman, Weija, the Laboratories of the Department of Zoology (now Department of Animal Biology and Conservation Science, DABCS), University of Ghana, Legon and some selected districts of Ghana. It was designed to; identify and establish the major Lepidopteran pests on cabbage, *Brassica oleracea* (L.) var. capitata and their parasitoids, determine the effect of the commonly used insecticides on parasitism and the biology of the major parasitoid, describe and illustrate the pests and their parasitoids to aid in identification. The rationale for the study was to provide information for implementation of effective integrated pest management in cabbage production in Ghana.

Field studies were carried out at the Weija site for three years. The design of the experiments was a randomized complete block design. Indirect and direct methods were used to investigate the effect of four insecticides namely, a synthetic pyrethroid (Karate), a *Bacillus thuringiensis* formulation, neem seed water extract and a commercial neem formulation, (Neemazal) on the major parasitoid. The illustrations were made using the scanning electron microscope, photomicroscope, a digital camera and Camera Lucida drawings.

The pests recorded were *Plutella xylostella* L., *Trichoplusia ni* (Hübner), *Hellula undalis* (F), *Helicoverpa armigera* (Hübner) and *Spodoptera littoralis* (Boisduval). *Plutella xylostella* was the most abundant pest recorded during the study period. There was no significant difference between its larval density per plant in the major rainy season (0.15 ± 0.04 , $p > 0.05$) compared with the minor rainy season (0.20 ± 0.07 , $p > 0.05$); and also between the minor rainy season and the dry season (0.29 ± 0.5 , $p > 0.05$). On the other hand, *T. ni* was only abundant during the major rainy season. There was a significant difference

between larval density per plant during this season (0.60 ± 0.11 , $p < 0.05$) compared with the other seasons. With regard to *S. littoralis*, there was a significant difference between its larval density per plant in the minor rainy season (0.39 ± 0.10 , $p < 0.05$) compared with the other seasons. The other pests occurred in insignificant numbers.

Out of the 15 species of parasitoids recorded from the pests, 7 were identified to the species level, 6 to the generic level and 2 to species groups. Seven of the species: *Charops* sp., *Brachymeria* sp., *Hockeria* sp., *Elasmus* sp., *Notanisomorphella* sp., *Tetrastichus atriclavus* S.L., *Pediobius* sp. and *Trichomalopsis* sp. were recorded for the first time in Ghana and may also be new species. The major parasitoid was *Cotesia plutellae* (Kurdjumov) which accounted for 92% and 60.9% of the parasitoids recorded from *P. xylostella* and *T. ni*, respectively. The second important parasitoid was *Euplectrus laphygmae* (Ferriere) and it was specific to *T. ni* and *S. littoralis*. The facultative hyperparasitoids of *P. xylostella* were *Oomyzus sokolowskii* (Kurdjumov), *Elasmus* sp., *Aphanogmus reticulatus* (Fouts) and *Trichomalopsis* sp. via *C. plutellae*. *Blepharella vasta* (Karsh), *Peribaea orbata* (Wiedemann), *Notanisomorphella* sp and *Chelonus curvimaculatus* (Cameron) were specific to the larvae of *S. littoralis*. No parasitoids were recorded from *H. armigera*. No egg parasitoid was observed.

There was seasonal variation in parasitism of *P. xylostella* by *C. plutellae*. The rate of parasitism ($68.6 \pm 12.9\%$, $p < 0.05$) was significantly highest in the major rainy season and significantly least ($9.9 \pm 7.1\%$, $p < 0.05$) in the minor rainy season. The rate of parasitism of *P. xylostella* by *C. plutellae* did not differ among the unsprayed and insecticide treated plots. However, adult *C. plutellae* emerging from pests collected from 'Karate' treated plots sometimes died in the process of eclosion or were short - lived. Neem seed water extract applied at 50 g/l also adversely affected the ability of the parasitoid larva to spin its cocoon for pupation. Of the three insecticides, 'Karate' was the most toxic causing 100% mortality

to the adult *Cotesia plutellae* within ten seconds of direct exposure. Neemazal and *Bt.* applied at 1.0% and 1.0g/liter of water respectively, were the least toxic to the adult.

It is concluded that *P. xylostella* is the major pest of cabbage in Ghana, while *T. ni* and *S. littoralis* are abundant only during the major and minor rainy seasons respectively. *Cotesia plutellae* and *E. lahygmae* are the major parasitoids and they should be considered in the development of any integrated pest management on cabbage. Karate has a harmful effect on *C. plutellae* adults. Even though, Neem seed applied at 50g/l adversely affected the development of *C. plutellae*, lower doses, or *Bacillus thuringiensis* formulations could be applied in the development of an Integrated Pest Management programme on cabbage.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

The common cabbage, *Brassica oleracea* L. var. *capitata* belongs to the family Brassicaceae, commonly referred to as the Brassicas. It is a native of the Mediterranean regions and Southern England, Wales and Northern France (Norman, 1992). Cabbage is thought to have evolved from a leafy, unbranched, thin-stemmed kale, *B. oleracea* but it is now cultivated throughout the world for its foliage bud (Prakash and Rao, 1997). It is a biennial herb with short thickened stem surrounded by a mass of overlapping expanding leaves, which form a compact head (Norman, 1992; Obeng-Ofori *et al.*, 2007). Cabbage is usually grown as an annual crop although it is a biennial, which can grow up to 90 cm (Watts and Watts, 1951). When left to complete its cycle, the crop will produce a large more or less dense head of leaves from a condensed stem in the first year, and then, an appreciable internode elongation will occur in the second year terminating in the formation of inflorescence (Norman, 1992). There is a great variation in the cultivated varieties of cabbage. They differ in shape, size and colour of leaves and size, and in the shape, colour and texture of heads. However, in the common cabbage, the leaves are relatively smooth and form a compact head.

Cabbage thrives best in a cool moist climate with temperature of 16-20 °C, but a number of varieties available now are well adapted to the tropics (Norman, 1992). There is no documented evidence as to when cabbage was introduced into Ghana. It is, however, believed to have been cultivated in the country as far back as the 1940's by the British (Sinnadurai, 1992). It may be grown throughout the year if irrigation or

other supplementary water is available. It is produced throughout the country, but of less importance in the Upper East Region (Timbilla and Nyarko, 2004). It is popular in the urban areas of Ghana where it is produced mainly by backyard and market gardeners (Ninsin, 1997). In the forest zone, it tends to grow better in the minor rainy season, but on the Accra plains, better yields are obtained during the main season. It does remarkably well at cooler mountainous areas of the country such as Akwapim and Kwahu, and the moist high elevations around Tarkwa in the Western Region (Bangnikon, 1996). Cultivars suitable for production in Ghana are Copenhagen Market, Drumhead, Suttons Tropical, Japanese Hybrid Cabbage, Golden Acre, Suttons Pride of the Market, KK Cross, Oxylus and Marion.

Cabbage is used raw in salads such as coleslaw, or as boiled vegetable. It is also used for cooked curries, pickles or sauerkraut. The older leaves discarded during harvesting are used as animal feed. Cabbage is fairly low in calories and proteins, but it is a good source of many minerals, particularly potassium, and it is relatively high in vitamins A, B and C (Norman, 1992). Yield of cabbage in Ghana varies according to the cultivar, weather and quantity of fertilizers applied. The average weight of an early maturing variety could be 1.5 kilogram per head. Thus, yield can vary from 18,000 kilograms per hectare for an early cultivar to 26,000 kilograms for a late cultivar (Obeng-Ofori *et al.*, 2007).

The cultivation of cabbage is threatened worldwide by the various lepidopterous pests that attack the crop (Oatman, 1966; Jusoh *et al.*, 1992; Pratisoli *et al.*, 2008) and cause extensive damage to it (Goodwin, 1979; Hamilton *et al.*, 2004). The major ones are the diamondback moth *Plutella xylostella* L., the cabbage looper, *Trichoplusia ni*

(Hubner), the imported cabbage worm, *Pieris rapae* (L.), the webworm, *Hellula undalis* (F.) and the cabbage head caterpillar, *Crociodolomia binotalis* Zeller (Smith and Brubaker, 1938; Harcourt, 1956; Sastrosiswojo and Sastrodihardjo, 1986; Walunj and Pawar, 2004; Obeng-Ofori *et al.*, 2007).

The control of these pests has depended mainly on the use of synthetic insecticides which has led to emergence of resistance and adverse effects on natural enemies (Verkerk and Wright, 1996; Ninsin, 1997; Dobson *et al.*, 2002). In addition, the increasing cost of chemicals (Obeng-Ofori, 2000; Youdeowei, 2002) and the very frequent application of cocktails without achieving control (Ooi and Sudderuddin, 1978; Sarfraz *et al.*, 2005) make alternative pest management strategies, especially biological control necessary (Abdel-Razek *et al.*, 2006).

Even though the diamondback moth, *Plutella xylostella* is considered the primary pest on cabbage, data on population trends and seasonal incidence are either lacking or poorly documented in many tropical countries (Kuwahara *et al.*, 1995). In Ghana, *P. xylostella*, *Trichoplusia ni* and *Hellula undalis* are considered serious pests on cabbage (Bangnikon, 1996; Obeng-Ofori and Ankrah, 2002; Obeng-Ofori *et al.*, 2007). However, there has neither been a systematic study on their seasonal incidence nor the occurrence of the other lepidopterous pests. Studies have been restricted to pesticide evaluations and a few short-term studies or observations on damage and behaviour. Virtually no study has been carried out to determine the correct identity, action and importance of the natural enemies of these pests on cabbage (Obeng-Ofori *et al.*, 2007). Much of the available literature is on *P. xylostella* and it is from South East Asia, the Americas and Europe (Harcourt *et al.*,

1955; Oatman and Platner, 1969; Talekar, 1992; Pratisoli *et al.*, 2008). It is therefore imperative that in Ghana, the seasonal incidence of the lepidopterous pests be determined, in order to provide a more sustainable basis for their management and to contribute to the existing body of knowledge. In this study, more emphasis will however, be placed on *P. xylostella*.

Population studies are important for determining the times of the year when damage is caused, the levels of parasitism of the pests of cabbage, appropriate timing for effective use of insecticides and other control measures (Kuwahara *et al.*, 1995; Liu *et al.*, 2000; Mosiane *et al.*, 2003). Generally, most of the field data on the relationships between parasitoids and host populations, lack a holistic approach (Guan-Soon, 1992). There is therefore, an urgent need for an in-depth study on the parasitoids in order to appreciate their role and to gain a better understanding of strategies that can be used to manipulate local populations (Mahr, 1996; Riba *et al.*, 1996; Pratisoli *et al.*, 2008).

The diamondback moth populations' native to different regions have morphological and biological differences, and specific parasitoid strains may be associated with the specific diamondback moth strains (Salinas, 1986; Sarfraz *et al.*, 2005). Incorrect identification and the difficulty of associating pests with parasitoids have led to numerous occasions when biological control has either failed or delayed (Yaninek and Herren, 1989; Bio-NET INTERNATIONAL, 1999).



The main objective of this study therefore, was to determine the incidence and seasonality of the major Lepidopteran pests of cabbage as well as the associated parasitoids and the levels of parasitism in southern Ghana.

The specific objectives were:

1. To determine the major Lepidopteran pests on cabbage in southern Ghana.
2. To determine the parasitoid-host associations in an annual production of cabbage and the effect of commonly used insecticides on parasitism and development of the dominant parasitoid.
3. To study the biology of the parasitoids with emphasis on the dominant one that could be used in an integrated pest management programme.
4. To describe the pests in relation to damage and behaviour on cabbage in southern Ghana.
5. To describe the parasitoids associated with the pests in southern Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Insect Pests of Cabbage

Cabbage, *Brassica oleracea* var. *capitata*, is a crucifer of economic value that is cultivated worldwide in both the tropics and temperate regions of the world. The crop supports a variety of insect fauna (Oatman and Platner, 1969; Talekar, 1992). Its successful cultivation is hampered by the incidence of various defoliating caterpillars (Srinivasan and Krishna-Moorthy, 1992; Hu *et al.*, 1997; CAB International, 1999). The major insect pests are the diamondback moth, *Plutella xylostella*, the cabbage looper, *Trichoplusia ni*, the imported cabbage worm, *Pieris rapae*, the webworm, *Hellula undalis*, the variegated grasshopper, *Zonocerus variegatus*, and the cabbage head caterpillar, *Crociodolomia binotalis* (Harcourt, 1956; Youdeowei, 2002; Obeng-Ofori *et al.*, 2007; Pratisoli *et al.*, 2008). Other pests recorded on cabbage include the corn earworm *Helicoverpa armigera* (Hubner), the African army worm, *Spodoptera exempta* (Walker), cabbage maggot *Hylemya brassica* (Bouche), cabbage flea beetles *Phyllotreta cruciferae* (Goeze), and cabbage aphids *Brevicoryne brassicae* (L.). One or more of these are considered occasional or seasonal pests in various countries (Boling and Pitre, 1971; Waterhouse, 1992; Poelking, 1992; Berg and Cock, 2000).

Plutella xylostella is considered the most destructive and occurs worldwide wherever cabbage and other crucifers are grown (Tadashi *et al.*, 1986; Pratisoli *et al.*, 2008). Attack by *P. xylostella* can lead to total destruction of the crop at all stages of plant

growth, and the production of unmarketable heads (Sachan and Srivastava, 1972; Loke *et al.*, 1992; Syed, 1992; Sivapragasam and Abdul Aziz, 1992).

The 1999 Annual Report of WEICO, a vegetable growing and irrigation company in Ghana and Obeng-Ofori *et al.* (2007) indicate that the diamondback moth is a serious pest in various parts of Ghana. Sometimes the crop is harvested prematurely or abandoned due to diamondback moth infestation (Cobblah, 2000).

Up to 1972, at least 128 countries or territories had reported the occurrence of *P. xylostella* (CAB International, 1999). It has been estimated that one billion US dollars is spent annually on its control worldwide in addition to the crop losses it causes (Talekar and Shelton, 1993; Vasquez, *et al.*, 1997; Abdel-Razek *et al.*, 2006).

The level of infestation of *P. xylostella* varies considerably (Harcourt *et al.*, 1955; Dennill and Pretorius, 1995). It is serious in S. E. Asia (Talekar *et al.*, 1992) and moderately so in parts of Canada and USA (Hardy 1938; Sutherland, 1966; Oatman and Platner 1969; Hill and Foster, 2000). In Germany and France, it is not present in sufficient numbers to be considered a serious pest (Lim, 1986) whilst in South Africa, it is ranked substantially low (Bell and McGeoch 1996; Kfir, 1997; Mosiane *et al.*, 2003). A study by Weires and Chiang (1973), found the diamondback moth to be dominant in only three locations while *Hellula undalis*, *Plusia orichalcea* (Hubner), *Agrotis ipsilon* (Hufnagel), *Helicoverpa armigera*, *Crocidolomia binotalis* and *Spodoptera* sp. were dominant in four locations (cited from Sastrodihardjo, 1986). Even though Koshihara (1986) recognised the diamondback moth as an important pest in Japan, the author observed that, prior to head formation, the imported cabbage

worm, *Pieris rapae* and the cabbage armyworm *Mamestra brassicae* (L.) could cause heavier visual leaf damage.

Hellula undalis is a major pest on cabbage seedlings in nurseries as well as transplanted young plants in the field in Guam (Muniappan and Marutani, 1992). It is of growing concern in the lowlands of Malaysia warranting serious attention (Sivapragasam and Abdul Azziz, 1992). However, Ooi (1979a) considered it as a minor pest in low altitudes with cooler temperatures as was observed in India (Sachan and Gangawar, 1980). In Hawaii, Jayma and Ronald (2007) observed that comparatively, the pest is not of great significance. Obeng-Ofori and Ankrah (2002) noted that *H. undalis* is a serious pest of cabbage in Ghana.

Trichoplusia ni is considered a serious pest in many parts of the USA and Canada (Chalfant, 1992; Wyman, 1992; Capinera, 1999) overshadowing the diamondback moth because of its voracious feeding habits (Hill and Foster, 2000). In Thailand it is considered as a minor pest, though potentially very damaging to young plants from seedling to bolting (Rowell *et al.*, 1992). The authors added that it appears to cause little damage after this stage. In Nigeria, the pest can reach epidemic levels on cabbage when not controlled (Anene and Dike, 1996). In Ghana, *T. ni* can cause considerable damage to the cabbage leaves and heart (Obeng-Ofori and Ankrah, 2002).

Crociodolomia binotalis, though a secondary pest of cabbage in Indonesia, can be a serious problem in the dry season (Sastrosiswojo and Setiawati, 1992) and is important at certain times of the year in Malaysia where it occurs with the

diamondback moth (Kadir,1992). Various species of armyworms such as *Spodoptera exigua* (Hubner) may be serious pests on cabbage in parts of S. E. Asia (Wakamura and Takai, 1992) but *S. littura* (F.) is seasonal in other countries (Muniappan and Marutani, 1992).

A list of major pests of cabbage worldwide is presented in Table 2.1.

Table 2.1 Major Pests of Cabbage and Damage Worldwide

Name of species	Order/Family	Damage & Part Attacked
<i>Plutella xylostella</i> (L.)	Lepidoptera/Plutellidae	Larvae feed on leaves
<i>Pieris rapae</i> (L.)	Lepidoptera/Pieridae	Larvae defoliate leaves
<i>Pieris canidia</i> (L.)	Lepidoptera/Pieridae	Larvae defoliate leaves
<i>Hellula undalis</i> (F.)	Lepidoptera/Pyralidae	Larvae eat growing points
<i>Agrotis ipsilon</i> (Hufnagel)	Lepidoptera/Noctuidae	Larvae are cutworms
<i>Agrotissegetum</i> (Schiffermuller)	Lepidoptera/Noctuidae	Larvae are cut worms
<i>Brevicoryne brassicae</i> (L.)	Hemiptera/Aphididae	Larvae Infest foliage
<i>Lipaphis erysimi</i> (Kaltenbach)	Hemiptera/Aphididae	Larvae infest foliage
<i>Aleyrodes brassicae</i> (L.)	Hemiptera/Aleyrodidae	Larvae infest foliage
<i>Delia brassicae</i> (Bouché)	Diptera/Anthomyiidae)	Larvae eat roots
<i>Aulacophora similis</i> (Olivier)	Coleoptera/Chrysomelidae	Adults chew leaves
<i>Phyllotreta</i> spp	Coleoptera/Chrysomelidae	Adults chew leaves
<i>Leucopholis irrorata</i> (Chevrolat)	Coleoptera/Scarabaeidae	Larvae chew roots
<i>Trichoplusia ni</i> (Hubner)	Lepidoptera/Noctuidae	Larvae defoliate plant
<i>Zonocerus variegatus</i> (L.)	Orthoptera/Acrididae	Chew leaves in nursery

Sources: Hill, 1983; Youdeowei, 2002; Obeng-Ofori and Ankrach, 2002

2.2 Origin and Distribution of the Pests

The most probable origin of the diamondback moth has been postulated to be the Mediterranean region (Hardy, 1938). This is based on circumstantial evidence that the largest contiguous area of its distribution is Europe, where the Brassicas had been cultivated since ancient times (Strasburger, 1921, cited in Hardy, 1938). The complex of natural enemies present there and the effective natural control reported lend support to this assertion (Ooi, 1986). It is likely that the diamondback moth was spread along with the spread of Brassicas from their original home. Kfir (1997) proposed that *Plutella xylostella* may have originated from South Africa. In addition to its effective control and the rich fauna of parasitoids which had been used as the basis for its European origin, the author argued that the lower pest status of the diamondback moth in South Africa compared with other countries with similar climates, the large number of indigenous Brassicas and parasitoids are more compelling reasons. However, Liu *et al.* (2000) indicated that the data from their study seem to add confusion to such speculations because most of the arguments used by Kfir (1997) seem to apply to China.

Only a few agricultural pests are as cosmopolitan as the diamondback moth and they have been recorded beyond latitude 60°N in Iceland in the temperate region and in the tropics (Ooi, 1986). It has the ability to survive a wide range of temperatures both in the tropic and temperate regions (Salinas, 1986). The pest is completely cosmopolitan in distribution, extending northwards up to the Arctic Circle (Frost, 1949; Hill, 1983) and to the Tropics (Talekar, 1992).

Trichoplusia ni is very widely distributed throughout the tropics and sub-tropics, with the exception of Australasia, and extends up into the warmer parts of southern Canada and Europe (Hill, 1983). It is found wherever crucifers are grown. It is highly dispersive and adults have sometimes been found at high altitudes and far from shore. Flight ranges of approximately 200 km. have been estimated (Capinera, 1999).

Hellula undalis was first identified in Italy but has now spread throughout the Middle East, Asia, North and West Africa, parts of Australia and to the Pacific islands (Hill, 1983; Muniappan and Marutani; 1992; Jayma and Ronald, 2007).

2.3 Description of the Pests

General descriptions of the developmental stages of the diamondback moth have been given by various workers (Hardy, 1938; Harcourt, 1956; Moriuti, 1986). However, the diamondback moth populations native to different regions have genetic and biological differences and the behavioural and morphological parameters of the developmental stages also vary (Salinas, 1972; Sarfraz *et al.*, 2005).

The adult is a small, slender, greyish-brown insect measuring 11 - 16 mm long with a wing span of about 10 mm (Hardy, 1938; Harcourt, 1956). It is also described as a greyish moth with a wing expanse of 14 mm, the male having an expanse of 12.97 mm and the female 13.0 mm (Chelliah and Srinivasan, 1986). The common name of the diamondback moth is based on the fact that, when at rest, the wings are closely applied to the sides of the body meeting above and presenting a slightly upturned diamond appearance at the rear end. Although colour variations occur, the females are generally lighter than the males (Harcourt, 1956; Moriuti, 1986).

The egg of the diamondback moth is described as yellowish white to yellowish green, cylindrical to oblong in shape, and measuring 0.48 mm by 0.25 mm (Bhalla and Dubey, 1986). It has also been described as whitish yellow with a length of 0.5 mm (Chelliah and Srinivasan, 1986). The larva may be whitish yellow to pale green or pale white with a pale brown head when freshly hatched (Chelliah and Srinivasan, 1986). The authors described the fully grown larva as light green, moderately stout, smooth, with short scattered hairs and varying in length from 8.62 to 10 mm. The pupa is light brown with a mean length of 5.15 - 7 mm (Harcourt, 1956; Bhalla and Dubey, 1986).

The adult of *Trichoplusia ni* is a dark brownish moth with a wing span of about 35mm (Hill, 1983). The forewings are mottled grey-brown in colour and the hind wings are light brown at the base, with the distal portions dark brown (Capinera, 1999). The forewing bears silvery white spots centrally: a U-shaped mark and a circle or dots that are often joined or resemble a figure '8' (Hill, 1983; Capinera, 1999).

The egg of *T. ni* is hemispherical in shape, with the flat side affixed to foliage (Capinera, 1999). The author described it as yellowish white or greenish in colour, bears longitudinal ridges and measures about 0.6 mm in diameter and 0.4 mm in height. The larva is basically green in colour, with a thin, white, lateral line and two white lines along the dorsal surface (Hill, 1983). The larva has three pairs of prolegs and move by arching its back to form a loop and then projecting the anterior section of the body forward. The thoracic legs and head are usually pale green and the mature larva measures about 3 - 4cm long (Capinera, 1999). The newly formed pupa

is green, but later turns dark brown or black. It measures about 2 cm in length (Capinera, 1999).

The developmental stages of the cabbage webworm, *Hellula undalis* have been described by (Jayma and Ronald, 2007). The authors described the adult as a greyish-brown moth with a wing span of about 2 cm. The forewings have wavy grey markings, a curved pale patch subterminally and a kidney shaped mark about one third way towards the tip. The eggs of the cabbage webworm are ovoid in shape and about 0.52 mm long. The surface attached to the foliage is slightly flattened. When freshly laid, it is pearly white but becomes pinkish after a day and then turns brownish red, just before hatching (Hrakly, 1968a; cited in Jayma *et al.*, 2007). The larvae are greyish - yellow with five broad, irregular reddish-brown bands that extend the length of the body. The pupae are about 12 mm long. The newly formed pupa is soft and pale yellowish, but becomes hard and light brown within a few hours.

2.4 Life History of the Pests

The life history and other aspects of the biology of the diamondback moth, *Plutella xylostella* have been documented by various workers (Harcourt, 1960a & b; Talekar and Griggs, 1986; Talekar, 1992). In general, an increase in temperature leads to a shortening of the developmental time of all stages up to a certain optimum depending on the area (Bhalla and Dubey, 1986; Salinas, 1986). In tropical conditions where temperatures range from 28 - 31 °C, the life cycle is completed within 14 - 24 days (Alam, 1992). 14 - 21 days have been reported by Harcourt (1957) in Canada, 10.8 - 27 days in Malaysia by (Ho, 1965) and 25.3 - 27.2 days in northern India by Yadav *et al.* (1974). Even in the same region, Ko and Fang (1979) reported only 9 days for a

single generation under favourable conditions while, in winter, one generation took 110 days.

The eggs are laid singly or in batches of up to four under the leaves (Bhalla and Dubey, 1986). Incubation period varies between 3 - 8 days and larval periods range from 6 - 17.5 days (Harcourt, 1957; Salinas, 1986). Four larval instars were recorded by Harcourt (1956) and Jayarathnam (1977), whilst Patil and Pokharkar (1971) recorded five instars. The fully grown larva spins an open net silken cocoon which is open at both ends, or a loose mesh of silken cocoon and pupates inside it on the leaf (Chelliah and Srinivasan 1986; Ooi, 1986). The pupal period is reported to vary from 4 - 15 days depending upon the temperature (Abraham and Padmanabhan, 1968; Salinas, 1986).

The adults are most active at dusk from 6.30 - 7.30 pm at temperatures of 20 - 21 °C and 90 - 95% relative humidity at which they mate and oviposit (Frost, 1949; Poelking, 1992). Longevity of the adults varies from location to location. Harcourt (1957) gave a range of 3 - 58 days for males and 7 - 47 for females whilst Salinas (1986) gave 8 - 16 days for females in the presence of the host plant, and 11 - 27 days in the absence of the host plant.

The life history of the cabbage looper, *Trichoplusia ni* has been studied by Hill (1983) and Capinera (2008). They observed that the number of generations completed per year overlap and varies from 2 to 5 depending upon the temperature. The total developmental period may take between 18 - 25 days at 32 - 21 °C respectively

(Capinera, 1999). The lower limit for development is about 10 - 12 °C and 40 °C is fatal to some stages.

The eggs of *Trichoplusia ni* are deposited singly on either the lower or upper surface of the leaf, although clusters of six to seven eggs are not uncommon (Capinera, 1999). The incubation period of the egg varies from 2 - 10 days and larval periods range from 20 - 35 days depending upon the temperature. Hill (1999) recorded five larval instars but, Capinera (2008) recorded four to seven instars. Pupation takes place in a white, thin, fragile cocoon formed on the underside of foliage, in plant debris, or among clods of soil. Capinera (1999) reported that the pupal period of *T. ni* takes 4 - 13 days depending upon the temperature.

The adults of *Trichoplusia ni* are considered to be semi-nocturnal because feeding and oviposition sometimes occurs around dusk (Capinera, 1999). Flight ceases at about 16 °C but activity is higher on warmer evenings (Hill, 1963; Capinera, 2008). The female oviposits readily at temperatures as low as 15.6 °C and may lay 300 – 600 eggs in her life time (Shorey, 1963).

The life history of the cabbage webworm, *Hellula undalis* was studied by Jayma and Ronald (2007) in Hawaii. They observed that the upper and lower threshold for development is about 36.6 °C and 20 °C respectively, and that the complete life cycle varies from 17 - 52 days.

The eggs are laid singly, or in groups of two or three on the leaves of cabbage near the bud. Incubation period of the egg varies from 2 - 3 days at a mean temperature of

27.8 °C (Awai, 1958; cited in Jayma and Ronald, 2007; Sivapragasam and Abdul Aziz, 1992). There are five larval stages which are completed in 14 days at 28 °C. Pupation occurs in a silken cocoon either in a tunnel constructed at the entrance of the feeding tunnel, between leaves, inside the stem and bases of dropped leaves or deep in the soil surrounding the plant. Pupal period lasts 8 days at 27.8 °C (Sivapragasam and Abdul Aziz, 1992).

The adults of *Hellula undalis* live for 4 to 8 days depending upon the temperature. Oviposition begins within 24 hours of emergence and continues for 3 to 10 days (Sivapragasam and Abdul Aziz, 1992).

2.5 Host Range of the Pests

The diamondback moth is an oligophagous insect that feeds on plants that contain mustard glucosides (Thorsteinson, 1953; Gupta and Thornsteinson, 1960). The cruciferous plants are an important economic group of plants with mustard glucosides, thus, wherever they are found, the diamondback moth is present (Ooi, 1986). In some cases, it is restricted to introduced or cultivated species of *Brassica* (Salinas, 1986). Being a crucifer specialist, it has adapted to the unique secondary chemistry of this family of plants that is toxic to most generalist feeders (Verkerk and Wright, 1996).

The diamondback moth has been observed as a major pest on Brussels sprouts in Canada (Butts and McEwen, 1981), radish, *Raphanus sativus* (L.) and watercress, *Nasturtium officinale* (Hill, 1983). Other host plants include collards (*Brassica oleracea* var *acephala* (L.)), Chinese cabbage, *B. campestris* L. subspecies *pekinensis* (Lour) Olsson, (Talekar and Yang, 1991), Broccoli, *Brassica oleracea* (L.) var

botrytis (Zhao *et al.*, 1992; Mitchell *et al.*, 1997a; Martinez-Castillo *et al.*, 2002). Mosiane *et al.* (2003) reported that in South Africa, canola, *Brassica napus* (L.) is a major host plant of the diamondback moth. In Ghana, it is associated with the cauliflower, *B. oleracea* var *botrytis* (L.), *B. oleracea* var *capitata* (L.) and *B. campestris* L. subspecies *pekinensis* (Obeng-Ofori *et al.*, 2007). Kmec and Weiss (1997) reported that this pest also occurred on the crop, crambe, *Crambe abyssinica* Hochst and the weed, field pennycress, *Thlapsi arvense* L. Other alternative hosts consist of a wide range of wild cruciferous plants (Hill, 1983). It had also been recorded on the non-crucifer, *Amaranthus viridis* L (Vishakantaiah and Visweswara Gowda, 1975) and on okra, *Abelmoschus esculentum* (L.) Moench (Gupta, 1991; Cobblah, 2000).

The cabbage looper, *Trichoplusia ni* feeds on a variety of crucifers and other cultivated plants and weeds. It has been reported damaging *Brassica oleracea* var *capitata*, *B. oleracea* var. *acephala*, *B. campestris* subspecies *pekinensis*, *Brassica oleracea* var *botrytis* in Canada and the United States of America (Harcourt, 1963; Capinera, 1999). It has also been recorded on cotton, tomatoes, legumes, sweet potato and water melon (Hill, 1983; Capinera, 1999). Capinera (1999) also noted that additional hosts are flower crops such as chrysanthemum, snapdragon and sweet pea and agricultural weeds such as wild lettuce, *Lactuca* spp.; dandelion, *Taraxacum officinale*; and curly dock, *Rumex crispus*. In Ghana, it is associated with the cauliflower, *B. oleracea* var *botrytis* and *B. oleracea* var *capitata* (Obeng-Ofori *et al.*, 2007).



Hellula undalis is host specific to cruciferous crops in Guam and it is associated with Chinese cabbage, *Brassica pekinensis*, green mustard, *B. juncea* and the common cabbage, *B. oleraceae* (Muniappan and Marutani, 1992). In Thailand, Australia, North and West Africa, and Hawaii it is recorded on various crucifer crops (Hill, 1983; Rowell, *et al.*, 2005; Jayman and Ronald, 2007). Obeng-Ofori *et al.* (2007) observed that in Ghana, *H. undalis* is associated with the common cabbage and cauliflower.

2.6 Damage by the Pests to Cabbage

The diamondback moth is the primary pest of cabbage worldwide and all the developmental stages occur on the plant. The behaviour and feeding damage caused by the pest have been described by (Talekar and Griggs, 1986; Talekar, 1992; Obeng-Ofori *et al.*, 2007). Its behaviour on the plant appears to be similar world-wide (Hardy, 1938; Harcourt, 1957; Sastrodihardjo, 1986). The newly hatched larva is essentially a leaf miner, forming shallow mines on the underside of the leaf and feeding in the spongy mesophyll (Dobson *et al.*, 2002). These show up as numerous white markings on the leaves. Hardy (1938) contended that this behaviour is not obligatory but, it is an adaptation enabling the young larva to consume as much parenchyma without the necessity of chewing through much of the toughened epidermis with its comparatively weak mandibles. When provided with tender thin leaves they do not mine but behave as surface feeders.

The subsequent instars are surface feeders, usually on the underside of the leaves. They chew all the leaf tissues with the exception of the veins and the upper epidermis, causing irregular transparent areas or patches on the leaves. This “windowing” effect

is distinctive of *P. xylostella* damage. The attack may begin from the seedling stage to maturity but there is a preference for the central leaves of young plants (Koshihara, 1986). They may also feed on the outer leaves. These feeding activities retard vegetative growth, render the heads unmarketable, and may lead to total destruction of the crop. When disturbed, even slightly, the larvae wriggle backwards or drop down unto the lower leaves by suspending themselves on a silken thread.

The larvae of the cabbage looper, *Trichoplusia ni* are leaf feeders and cause considerable damage to cabbage. The first three instars confine their feeding to the lower leaf surface leaving the upper surface intact (Capinera, 1999). The author also observed that the fourth and fifth instars chew large holes in the leaf, and feed on the wrapper leaves as well as the developing head. Obeng-Ofori *et al.* (2007) noted that the larvae bore irregular holes in the leaf lamina and attack the newly formed heads resulting in numerous feeding punctures that are filled with frass. Even though, the larvae are voracious and consume three times their weight in plant material daily, they are not always destructive (Capinera, 1999). In Thailand, *Trichoplusia ni* can be potentially damaging to young plants from the seedling stage until bolting, but appears to cause little damage to the seed crop thereafter (Rowell, *et al.*, 1992). On the other hand, Prasad (1963) observed that *T. ni* reduced yield of marketable crop by 64 - 78%. In the United States of America, moderate defoliation prior to head formation is irrelevant, but average population densities of 0.3 larvae per plant justify control (Kirby and Slosser, 1984; cited in Capinera, 1999).

The larvae of *Hellula undalis* cause damage to the terminal shoots and midribs of leaves, and in severe cases, such damage result in the development of multiple heads,

which are small and unmarketable (Muniappan and Marutani, 1992). It may cause occasional damage to young plants in the pre-flowering stage (Rowell, *et al.*, 1992). Sivapragasam and Abdul Azziz (1992) observed that damage is most severe between transplanting and the heading stage of cabbage, even though, the larvae are present in the field throughout the crop. Severe damage or death occurs when the larvae tunnel into the main stem (Jayma and Ronald, 2007). In Ghana, Obeng-Ofori and Ankrah (2002) reported that the larvae of *H. undalis* attack the leaves, stalk and heart of cabbage, and also spin together the leaves with silken thread.

2.7 Seasonal Incidence of the Pests

Incidence and population trends vary for the various lepidopterous pests on cabbage. Seasonal incidence of the diamondback moth in relation to various factors has been described (Harcourt, 1957; Sachan and Srivastava, 1972; Butts and McEwen, 1981). In general, dry and warm weather triggers outbreaks (Sastrodihardjo, 1986) or favours population build up (Frost, 1949; Oatman and Platner, 1969; Alam, 1992). Similar trends have been found in India (Abraham and Padmanabhan, 1968; Yadav *et al.*, 1974). In India, Rustapakornchai and Vattanatangum (1986) also recorded high build-up of the larvae in the summer, dry season and the mid-rainy season whereas Nagarkatti and Jayanth (1982) recorded significantly higher build-up during the rainy season, compared with other seasons.

Observations by several workers indicate that temperature is a limiting factor in the population dynamics of the diamondback moth. A high temperature of 33 °C led to low survival rates as it adversely affected the development and emergence rates (Wakisaka *et al.*, 1992). Dennill and Pretorius (1995) reported 10.5 °C and 25.8 °C as

being within the critical limit. Koshihara (1986) reported a daily minimum range of 5 - 12 °C and a maximum of 21 - 36 °C as favourable for multiplication of the diamondback moth. The diamondback moth may occur all year round (Harcourt, 1963) and even in winter at a minimum temperature of 10 °C, but the population densities differ (Koshihara, 1986). The number of generations is higher in the hot lowlands than in the highlands of Thailand and survival rates are higher in the hot dry season than in the wet season (Keinmeesuke *et al.*, 1992). Humidity has little influence on the development and survival, as the immature stages live in specialised microclimate (Hardy, 1938).

The population of the diamondback moth is high early in the cropping season (Harcourt, 1986), peaking at 45 days after transplanting (Sastrodihardjo, 1986; Rowell *et al.*, 1992), or before cupping (Chalfant *et al.*, 1979; Dennill and Pretorius, 1995; Mosiane *et al.*, 2003) and declining thereafter. The diamondback moth is a multivoltine species and several generations overlap in a single crop or annually, making it very difficult to study its life cycle in the field. In warm parts of Japan and South East Asia, up to 15 and 20 generations overlap annually (Talekar and Griggs, 1986; Poelking, 1992).

The incidence of attack and population densities vary widely within plants and even within fields in the same growing season (Harcourt, 1960a, 1961; Hu *et al.*, 1997). In certain areas of South Africa, 11.6 larvae per plant was observed by Ulliyet (1947) while Denill and Pretorius (1995) recorded 0.42 larva per plant. Peaks of 1.6 to 3.6 larvae/plant in four seasons were reported by Oatman and Platner (1949) with pupae following the same trend. Densities of 2.5 - 20 larvae per plant had been recorded by

several workers in different areas (Prasad, 1963; Baker *et al.*, 1982; Simonet and Murisak, 1982; Andaloro *et al.*, 1982). High densities of 477 larvae/plant in an outbreak period and mean population densities of 2 to 78 larvae/plant, with a maximum of 160 larvae/plant, were reported by Wan (1970) and Ooi (1979a & b), respectively. Harcourt, *et al.* (1955) observed a mean population build up of 14.9 to 26.9 larvae/plant by the end of harvest. The infestation of cabbage by the diamondback moth varied from 5% to 100% in the growing season whilst between 3% and 73% of plants were infested with larval populations ranging between 3 and 415 per 100 plants (Prasad, 1963; Sachan and Srivastava, 1972).

Weeds have been shown to maintain *Plutella xylostella* populations during the off-season periods. Kmec and Weiss (1997) observed that, peak populations occurred first on weeds before the moths move onto the cultivated crop. Larval densities were higher on rows adjacent to weeds and bushes than in the interior of fields but these varied among fields (Hu *et al.*, 1997).

With regard to *Trichoplusia ni*, temperature has been found to be a limiting factor in its incidence and activity. Hill (1983) observed that in temperate areas the larvae continue to be active at low temperatures; generally flight ceases at about 16 °C and larval development at about 12 °C. In warm regions however, there may be 5 generations per year or more as a result of continuous breeding. Overwintering of the pest apparently occurs only in the southernmost states of the USA; it is erratic in occurrence, typically very abundant in one year, and then scarce for two to three years (Capinera, 1999). The author also noted that, the number of generations per year overlap and varies from two to seven. In Nigeria, Anene and Dike (1996) observed

that populations were high during the rainy season and could reach epidemic levels. On the other hand, Hofmaster (1961) cited in Capinera (1999) reported that cabbage looper populations in Virginia were highest during dry weather because rainfall assisted the spread of Nuclear Polyhedrosis Virus (NPV), which greatly suppressed the population. In India, populations of *T. ni* reach their peak by early September and remain high till the last week, and then declines greatly up to February. During the peak period 32% of plants are infested (Sachan and Srivastava, 1972). Wyman (1992) noted that in Central North America, populations were high in all fields in mid to late season. Chalfant *et al.* (1997) also reported that populations of the pest were heaviest after cupping until harvest.

The adults of *Hellula undalis* are primarily active at night (Jayma and Ronald, 2007). Populations reach their peak by about middle of August, declines during October, and it is negligible in winter in India (Sachan and Srivastava, 1972). Wyman (1992) noted that in Central North America *H. undalis* occurs in small numbers sporadically throughout season.

2.8 Mortality Factors Influencing the Survival of the Pests

2.8.1 *Plutella xylostella*

Factors affecting the abundance of the diamondback moth have been studied by a number of workers (Hardy, 1938; Harcourt, 1963; Kmec and Weiss, 1997). The major mortality factors are parasitoids and rainfall (Harcourt, 1963; Lim, 1986; Keinmeesuke *et al.*, 1992; Capinera, 2005). However, Hardy (1938) suggested that rainfall may be important only at certain critical periods in the life cycle and argued that temperature was more critical.

2.8.1.1 Rainfall

The effect of rainfall is manifested by washing away and/or drowning of early instar larvae and eggs (Wakisaka *et al.*, 1992; Capinera, 2005) and causing mortality of gravid females (Harcourt, 1963; Talekar *et al.*, 1986). Harcourt (1963) found a positive correlation between intensity of rain and mortality of the diamondback moth, while Rowell *et al.* (1992) observed low diamondback moth populations after the rains.

2.8.1.2 Parasitoids

All the developmental stages of the diamondback moth are attacked by parasitoids. Only a few species have been reared from the eggs and they belong to the genera *Trichogramma* and *Trichogrammatoidea*. These however, contribute little to mortalities in the diamondback moth (Yamada and Yamaguchi, 1985; Waterhouse, 1992; Alam, 1992). The greatest control is provided by the endo-larval parasitoids (Ooi, 1970; Talekar, 1992; Liu *et al.*, 2000; Mustata *et al.*, 2006). The main larval parasitoid species that are reported to cause significant mortalities belong to the Hymenoptera genera, *Diadegma* Foerster (Ichneumonidae), *Microplitis* Foerster and *Cotesia* Cameron Braconidae (Waterhouse and Norris, 1987; Waladde *et al.*, 1997; Rowell *et al.*, 2005). Even though, the importance of the different genera varies from place to place (Mustata, 1992), several accounts on parasitism of the diamondback moth indicate that, of the three genera, *Diadegma* species are superior to the others (Putnam, 1968; Sastrosiswojo and Sastrodihardjo, 1986; Talekar *et al.*, 1992). As a result of this observed superiority, *Diadegma* species have been introduced into several countries, sometimes to augment the impact of other species of the genus

Cotesia or some other indigenous species (CIBC, 1977; Ooi and Chua, 1986; Lim, 1986).

The degree of parasitism varies from species to species and from country to country, or even from locality to locality in the same area (Hardy, 1938; Ooi, 1992; Talekar *et al.*, 1992; Mustata, 1992). Some species can be effective under specific conditions and yet ineffective under other conditions even in the same field or year (Salinas, 1986).

The three most important species of *Diadegma* are *D. (Angita) eucerophaga* Horstm, *D. insulare* (Cress) and *D. semiclausum* (Hellèn) (Sastrodihardjo and Sastrosiswojo, 1986; Ooi and Chua, 1986 and Alam, 1992). A number of reports exist on the widespread occurrence of *Cotesia (Apanteles) plutellae* Kurdjumov in many countries (Chiu and Chien, 1972; Ooi, 1979b&c; Loke *et al.*, 1992; Ingham and Kfir, 1997). However, in Indonesia and Central America, it is not common (Waterhouse, 1992; Andrews *et al.*, 1992.). Reports and observations from laboratory studies regarding the superiority of *D. semiclausum* over *C. plutellae* contradict some field and laboratory observations. Despite *D. semiclausum* being intrinsically superior to *C. plutellae*, the latter is more dominant in field studies (Ooi, 1992).

Hyperparasitoids broadly defined as parasitoids that seek parasitized hosts and lay their eggs into the host or into the developing parasitoid within the host (Greathead *et al.*, 1992) have been suggested as contributing to the apparent ineffectiveness of *C. plutellae* and its inability to establish in the field (Ooi, 1979a; Lim, 1982; Alam, 1992; Morallo-Rejesus and Sayaboc, 1992). Ooi (1979c & d) reared eight hyperparasitoids

from field collected cocoons of *C. plutellae* and observed hyperparasitism levels of between 11.7 - 26.6% whilst Lim (1982) recorded an average of 21%. High hyperparasitism rates of 56% (Alam, 1992) and 80% - 90% (Poelking, 1992) by *Spilochalcis* sp. on *C. plutellae* have also been recorded. Ten different species of hyperparasitoids belonging to nine genera had been reared from *C. plutellae* by Chelliah and Srinivasan (1986), Liu *et al.* (2000), and Mosiane, *et al.* (2003). Of these, the important ones were *Aphanogmus fijiensis* Ferriere (Ceraphronidae), *Hockeria atra* Masi (Chalcididae), *Pediobius imbreus* Walker (Chalcididae), *Pteromalus* sp. (Pteromalidae), *Tetrastichus* sp. (misre group) (Tetrastichidae), *Brachymeria excarinata* (Gahan) (Chalcididae), and *Tetrastichus sokolowskii* Kurdjumov (= *Oomyzus sokolowskii*), with the last two acting as facultative hyperparasitoids. They also found the lowest hyperparasitism level of 3 - 13% and the highest of 39.13%. This high level of hyperparasitism coincided with peak parasitism by *C. plutellae* on the diamondback moth. Morallo-Rejesus and Sayaboc (1992) recorded *Trichomalopsis* sp. as an important hyperparasitoid reducing the efficiency of *C. plutellae*. The negative effect of hyperparasitoids has, however, been disputed by other workers who noted that their effects are of little significance (Robertson, 1939), and of no economic impact (Mustata, 1992; Mustata *et al.*, 2006). The commonest pupal parasitoids belong to the Ichneumonid genus *Thyraella* (= *Diadromus*), and the Eulophids *Tetrastichus* Haliday and *Oomyzus* Rondani. The only one with potential for biological control of the diamondback moth is the facultative hyperparasitoid *Oomyzus sokolowskii* Kurdjumov (Fitton and Walker, 1992; Liu *et al.*, 2000). It is a gregarious larval-pupal parasitoid exhibiting a density independent relationship with the diamondback moth (Ooi and Chua, 1986; Alam,

1992). However, *T. ayarri* (Olliff) was regarded as a common parasitoid of the diamondback moth in S. E. Asia (Ooi, 1986; Fitton and Walker, 1992).

2.8.2 *Trichoplusia ni*

The cabbage looper *Trichoplusia ni* is attacked by numerous natural enemies, and the effectiveness of each seems to vary greatly. Wasp and tachinid parasitoids, and a nuclear polyhedrosis virus (NPV) have particularly been noted to be effective (Capinera, 2008). The author noted that predation on the pest has however, not been well studied.

2.8.2.1 Parasitoids

Egg parasitism by *Trichogramma* sp., though variable, could reach about 35% in California (Oatman and Platner, 1969). Hill (1983) reported that high field mortality of *Trichoplusia ni* can sometimes be attributed to parasitoids. Larval parasitism has been found to average 38.9% with the tachinid *Voria ruralis* (Fallen) being the dominant species in autumn and winter months (Capinera, 2008). Even though, a total of twenty four parasitoid species were observed, the authors concluded that they are not key factor affecting populations.

2.8.2.2 Nuclear Polyhedrosis Virus

The *Trichoplusia ni* NVP is reported to be the key factor affecting populations of the pest in California (Oatman and Platner, 1969). However, Sutherland (1966) observed that in New York, although *T. ni* NVP is an important mortality factor, natural incidence does not appear to be adequate to protect the crop from damage. The erratic

occurrence and abundance of the pest in parts of the USA has been attributed to the nuclear polyhedrosis virus which is spread by rain (Capinera, 1999).

2.8.3 *Hellula undalis*

Very little is known regarding the mortality factors that influence populations of the cabbage webworm. In Hawaii, Zimmerman (1958) cited in Jayma and Ronald (2007) reported that *Chelonus blackburni* Cameron is an egg - pupal parasitoid of the pest. However, its importance in managing webworm population densities is unknown.

2.9 Control Measures Against the Pests

Several control measures have been applied against the major Lepidopteran pests of cabbage, especially the diamondback moth in many countries. Simonet and Morisak (1982) observed that several factors have to be considered in a pest management programme for cabbage feeding caterpillars. Capinera (1999) and Jayma and Roanld (2007) on the hand proposed that management strategies should include consideration of the complex of crucifer-feeding caterpillars. The control measures include the use of various insecticides, biological control, resistant varieties, pheromones, cultural and physical methods or combinations of these.

2.9.1 Chemical Control

In many countries, attempts to control *P. xylostella* have been by the use of synthetic insecticides (Chelliah and Srinivasan, 1986; Wyman, 1992). These include relatively new chemicals such as avermectins, neonicotinoids and insect growth regulators (Abdel-Razek *et al.*, 2006), microbial insecticides such as *Bacillus thuringiensis* Berliner (*Bt*) (Mahar *et al.*, 2004; Abdel-Razek *et al.*, 2006) and plant based products

such as neem, *Azadirachta indica* A. Juss (Verkerk and Wright 1996; Rowell *et al.*, 2005; Condor 2007).

In Ghana, the main synthetic insecticide used is lambda cyhalothrin formulated as Karate 2.5% EC (Obeng-Ofori and Ankrah, 2002). Other types are Dimethoate (400g/l) and Fipronil (25 g/l) (Koomson, 2008). *Bacillus thuringiensis* (*Bt.*) based products are also commonly used (Cobblah, 2000). Extracts of seed, kernel, or leaves of neem have been found to be effective against *P. xylostella* (Barnby *et al.*, 1989; Schmutterer, 1992; Verkerk and Wright 1996; Youdeowei, 2000; Charleston, 2002). Water extracts have proven to be most effective at concentrations as low as 12.5 g of seed per litre of water (Youdeowei, 2000). The use of neem seed water extract against the diamondback moth is common in some regions in Ghana according to Obeng-Ofori and Akuamoah, (1998). Morallo-Rejesus (1986) and Charleston *et al.* (2005) listed 88 plants mainly of the families Asteraceae, Euphorbiaceae and Meliaceae as having some insecticidal action against the diamondback moth.

In parts of Asia and Africa, farmers use cocktails of insecticide and spray more frequently without satisfactory control (Muckenfuss *et al.*, 1992; Obeng-Ofori, 2000; Lohr, 2003; Mosiane *et al.*, 2003). The pest is now widely known to have become resistant or tolerant to most insecticides such as Esfenvalerate, Diazinon, Permethrin (Miyata *et al.*, 1986; Beck and Cameron, 1992; Walunj and Pawar, 2004). Some populations of the diamondback moth have developed resistance to certain *B. thuringiensis* based products (Tanaka, 1992, Tabashnik *et al.*, 1992). However, of all the commercial biopesticides, *Bt* constitutes the most significant control option (Cherry *et al.*, 2002).

The cabbage looper, *Trichoplusia ni* is the most difficult crucifer pest to control in parts of the USA and chemical control is difficult to achieve (Chalfant *et al.*, 1979). Hill (1983) reported that the pest is resistant to carbaryl, parathion and methomyl. Capinera (1999) observed that even though, insecticide resistance is a problem in cabbage looper control, susceptibility varies widely among locations. In Thailand, *Bacillus thuringiensis* Berliner (Florbac FC, 8500 IU/mg) is used exclusively for control of *T. ni* (Rowell *et al.*, 1992). Botanical insecticides such as rotenone are less effective, but neem functions as both a feeding deterrent and growth regulator (Capinera, 1999). Wyman (1992) reported that one to two applications of esfenvalerate provided excellent control. Obeng-Ofori and Ankrah (2002) reported that Neem extracts have great potential against several pests on cabbage in Ghana. The authors indicated that neem seed applied at the rate of 50 g/litre of water can be used as an alternative to synthetic insecticides to control cabbage pests and that, 300g of neem leaves and 100 g of hot pepper/litre of water are effective.

With regard to chemical control of the cabbage webworm *Hellula undalis*, Jayma and Roanld (2007) have drawn attention to the difficulty of chemical sprays penetrating the webbing produced by the larvae on cabbage. However, Rowell *et al.* (1992) reported that in Thailand, mevinphos (Phosdrin, 24EC) is effective in controlling the pest. In Guam Dibrom 8 EC has been observed to be most effective, providing 100% control (Muniappan and Marutani, 1992). Tests of *Bacillus thuringiensis* in Hawaii and elsewhere suggest that, they are only partially effective, and it is not recommended as standard treatments (Jayma *et al.*, 2007).

2.9.2 Biological Control

Biological control, which involves principally the introduction, augmentation and conservation of natural enemies, is a valuable weapon in pest control on a number of crops. Biological control may be the exclusive method of control (Verkerk and Wright, 1996), or integrated with other methods such as the use of insecticides in some geographic areas and at certain times within the crop cycle (Loke *et al.*, 1992; Lim, 1992; Klemm and Schmutterer, 1993).

Although over 130 species of parasitoids are known to attack various life stages of the diamondback moth, most worldwide control is achieved by relatively few Hymenopteran species belonging to the Ichneumonid genera, *Diadegma* and *Diadromus*; the Braconid genera *Microplitis* and *Cotesia*; and the Eulophid genus *Oomyzus* (Mahmood *et al.*, 2004; Sarfraz *et al.*, 2005). The use of parasitoids alone has led to varying degrees of success (Mitchell *et al.*, 1997a & b; Rowell *et al.*, 2005; Mustata *et al.*, 2006). Complete and partial controls of the diamondback moth by *Cotesia plutellae* have been reported in the Cape Verde Islands and Togo, respectively (Carl, K. P. British Museum Natural History personal communication).

Biological control of the eggs of *Plutella xylostella* varies from country to country. Liu *et al.* (2000) noted that rates of parasitism of the diamondback eggs by *Trichogramma chilonis* Ishii was very low and did not go beyond 1 - 11% in the suburbs of Hangzhou, China. According to Haji *et al.* (2002, cited in Pratisoli *et al.*, 2008), the use of *Trichogramma* species is increasing because it is cheap and easy to mass produce and can quickly suppress pest populations prior to crop damage. Laboratory evaluation of three species of *Trichogramma* was done to identify the most suitable for use in

biological control programmes showed that *T. atopovirilia* (Oatmam and Platiner) had the strongest affinity for the eggs of the diamondback moth causing 42.33% parasitism (Pratissoli *et al.*, 2008). Mass release of *Trichogrammatoidea bactrae* Nakaraja in Thailand in the 1990's caused parasitism of between 16 - 45% of the diamondback moth eggs in unsprayed fields (Rowell, 2008).

Eighty percent parasitism of the larvae of the diamondback moth by *Diadegma eucerophaga* was reported by Sastrosiswojo and Sastrodihardjo (1986) and also by Ooi and Chua (1986); but Sastrodihardjo (1986) reported a low rate of below 30%. A combination of *D. insulare* and *Microplitis plutellae* (Mues) caused 68% parasitism in the first generation of the diamondback moth in Canada (Putnam, 1968). In the Philippines, the introduction of *Diadegma semiclausum* led to a reduction of the diamondback moth infestation from an average of 18.7 larvae/plant to 9.8 larvae/plant (Poelking, 1992).

Ooi (1986) observed that even though *Cotesia plutellae* reduced the diamondback moth populations by 47 fold in the laboratory, field studies suggested limited ability of the parasitoid to control this pest because of its poor searching ability. Despite this, some introductions of this species have been successful (Muniappan and Marutani, 1992). In Central America, attempts to complement the native *Diadegma insulare* (Cresson) with exotics have not been successful, but *C. plutellae* had been introduced and occasional recoveries made (Andrews *et al.*, 1992). In the Caribbean, parasitism by the indigenous *C. (Apanteles) glomeratus* group was found to be low and erratic with the highest parasitism of 5%. However, the introduction of *C. plutellae* resulted

in parasitism of between 5.4 and 88.7% resulting in a marked reduction in the diamondback moth population (Alam, 1992).



Wide variations in parasitism by *C. plutellae* had been reported from locality to locality and from country to country, even in areas with similar climates (Yaseen, 1978; Ooi and Chua, 1986). Most reports indicate that the level of parasitism by *C. plutellae* cannot exceed 60% (Ooi, 1979a & b; Ooi, 1992). It had been reported as the commonest parasitoid in Malaysia causing only 12 - 19%, or an average of 14.4% with a range of 0 - 33% (Ooi and Chua, 1986). Poelking (1992) reported 1 - 70% parasitism over different locations, seasons and years in the Phillipines whilst Morallo-Rejesus and Sayaboc (1992) recorded percentages between 1.9 - 16.5 in the same country. The latter authors also indicated that different strains have different abilities to parasitise, with exotic ones being superior. In the lowlands of Malaysia, parasitism by *Cotesia plutellae* ranged from 12.7 - 48.6% (Loke *et al.*, 1992). Martinez-Castillo *et al.* (2002) reported that in Central Mexico, biological control of *Plutella xylostella* larvae by *Diadegma insulare* could reach as high as 42.7% on cabbage.

Cotesia plutellae was not effective in places where percentage parasitism was between 2.3 and 35.8% but, in areas where parasitism ranged from 59.3 - 66.6%, it was very effective in keeping the diamondback moth populations in check (Ooi, 1992). A high level of parasitism of 78.8% at both larval and pupal threshold of about 3 per plant was reported by Ooi (1986), but this was attributed to low host numbers. This author, however, noted that *C. plutellae* was not effective and could not prevent pest numbers from rising in the dry season. On the contrary, Ingham and Kfir, (1997)

indicated that parasitism by *C. plutellae* was effective when the diamondback moth populations were high. A combination of various parasitoid species had also given very good results (Yaseen, 1978; Ooi and Chua, 1986). *Cotesia plutellae* and *O. sokolowskii* had been reported to cause 10 - 60% larval parasitism at peak populations of the diamondback moth in parts of China and Romania (Liu *et al.*, 2000; Mustata *et al.*, 2006). In Kenya, the indigenous parasitoid species of *Diadegma* and *Itopectis*, *O. sokolowskii* and an unidentified braconid caused a total of 20.8% parasitism while in Tanzania, *C. plutellae*, *D. mollipla* and *O. sokolowskii* caused a total of 10.1% parasitism (Lohr, 2003). This author also reported that the introduction of the exotic larval parasitoid *D. semiclausum* into these countries surpassed the combined parasitisation of *P. xylostella* by the indigenous parasitoids.

High levels of parasitism of the diamondback moth by pupal parasitoids belonging to the genera *Tetrastichus* and *Diadromus* (= *Thyraella*) Gravenhorst have been reported (Ooi and Kelderman, 1977; Keinsmeesuke *et al.*, 1992). In several countries of South East Asia *D. collaris* has been reared and released and contributes significantly to natural control of the diamondback moth pupae (Rowell, 2008). *Oomyzus sokolowskii* caused parasitism levels of up to 100% and 10% when acting as a primary or secondary parasitoid, respectively (Cock, 1985). Liu *et al.* (2000) reported secondary parasitism of 18% of the diamondback moth by this species in the laboratory. Mustata *et al.* (2006) considered *O. sokolowskii* as a dominant and constant secondary parasitoid in the field in Romania. Its ability to also act as a hyperparasitoid does not make it a bad candidate as a primary parasitoid (Waterhouse and Norris, 1987; Mustata *et al.*, 2006). This species was also the most abundant species recorded by other workers (Yaseen, 1978; Alam, 1992; Waiganjo, 1997). It

had also been used in combination with other species (Ooi, 1980; Chellia and Srinivasan, 1986) but very low parasitism rates ranging from zero to a maximum of 20% were noted after the initial rate of 100%. *Diadromus collaris* Gravenhorst occurred when the diamondback moth populations were low late in the growing season and in the dry season when temperatures were high (Andrews *et al.*, 1992; Rowell *et al.*, 1992). Ooi and Kelderma (1977) and Ooi (1979a & b) considered *Tetrastichus ayyari* Rohw (= *T. howardi* = *T. Israeli*) to be of little importance as it occurred in negligible numbers.

Mass release of *Trichogramma* spp. has been investigated for *Trichoplusia ni* suppression. Oatman and Platner (1971) cited in Capinera (1999) observed that cabbage looper egg parasitism can be increased several fold by careful timing of the parasitoid release.

Baculoviruses have long been recognized as safe and effective biological pesticides for the control of Lepidopteran pests and in West Africa the baculoviruses of *Plutella xylostella* are amenable to mass production and field application (Cherry, 2001). To a limited extent, baculoviruses have been used (Kadir, 1992; Cherry, *et al.*, 2002). Osaë *et al.* (2006) found that an East African strain of baculovirus was effective against a West African population of *P. xylostella*.

Trichoplusia ni NVP is effective, but has not been commercialised because of the narrow host range (Capinera, 1999). The author observed that home gardeners in parts of the United States of America sometimes collect and grind loopers dying of the virus, and concoct their own effective microbial control agent.

The practice of biological control has however, been hindered in some countries by the overuse of insecticides leading to ineffectiveness of *Cotesia plutellae* and other parasitoids of the diamondback moth in the cabbage ecosystem (Mustata, 1992; Waiganjo, 1997). The effects of insecticides on all developmental stages of parasitoids of the diamondback moth had been documented in parts of Asia and the USA (Keinmeesuke *et al.*, 1992; Kao and Tzeng, 1992; Hu *et al.*, 1997; Hill and Foster, 2000; Charleston *et al.*, 2005). However, very little information exists on the effects of insecticides on parasitoids of the diamondback moth in Ghana (Obeng-Ofori, 2000).

Different authors have given contradictory observations on the adverse effects of insecticides on *C. plutellae*. Poelking (1992) noted that it resulted in reduced efficiency. Mustata (1992) and Waiganjo (1997) also attributed low levels of parasitism by a complex of diamondback moth parasitoids to the overuse and continued use of broad spectrum insecticides. Similarly, Alam (1992) noted that the failure of *Cotesia plutellae* to establish themselves in the field could have resulted from excessive use of chemicals. Some reports, however, indicated that the species was either tolerant or had achieved a certain level of resistance to insecticides in the field (Ooi, 1992; Liu *et al.*, 2000; Rowell *et al.*, 2005). In a field survey, Loke *et al.* (1992) recorded a high mean parasitism of 48.6%, even under very heavy insecticidal pressure. A mean parasitism of 75% by *C. plutellae* on the diamondback moth larvae was observed in spite of 1 - 3 weekly applications of insecticide cocktails (Lim, 1992). Liu *et al.* (2000) similarly observed substantial rates of parasitism by the parasitoid on many occasions in China despite the heavy application of insecticide into the crop system. Intermittent *Bacillus thuringiensis* (*Bt*) sprays led to a reduction

in parasitism by *C. plutellae* (Morallo-Rejesus and Sayaboc, 1992). A strain, NRD-12 (SAN 415) of *Bt* s.sp *kurstaki* was found to be more harmful to adults of *C. plutellae* than *Bt* s.sp *kurstaki* strain HD-1 (Kao and Tzeng, 1992). In addition, it has been observed that even though most of the other synthetic insecticides were harmful to the adults, the pupae were relatively tolerant (Mani and Krishnamoorthy, 1984).

Diadegma insulare seems to be less tolerant to pesticides than *C. plutellae*. Reduction of chemical insecticides allowed its full potential of to be realized, with *C. plutellae* becoming less dominant (Ooi, 1992). The inability of *D. insulare* to establish in some parts of Malaysia was reported to be partly due to high levels of insecticide use (Talekar *et al.*, 1992). Hill and Foster (2000) observed that the *Actinomycetes*-derived product, Spinosad caused 100% mortality to adults of *D. insulare* after eight hour exposure to leaves treated with the chemical. The effectiveness of *Diadromus collaris* (Gravenhorst) was reduced from 63% to 31% due to frequent use of broad spectrum insecticides (Rowell *et al.*, 1992); but *Bacillus thuringiensis*, was found to exert less adverse effect it (Ooi, 1992). Keinmeesuke *et al.* (1992) observed that, even though *Bt* and certain synthetic insecticides had low toxicities to adults of the diamondback moth and the egg parasitoid, *Trichogramma bactrae*, few others were highly toxic to the diamondback moth eggs parasitised by this species and led to low emergence.

3 Integrated Pest Management

The problems associated with controlling *P. xylostella* and other Lepidopteran pests of cabbage with insecticides alone have stimulated interest in the use of a combination of strategies (Reddy and Guerrero, 2000; Lohr, 2003). Examples of successful

Integrated Pest Management (IPM) strategies abound in the literature (Talekar and Griggs, 1986; Lim, 1990; Talekar and Yang, 1991; Liu, 2001). There is also widespread recognition of the crucial role played by natural enemies (Hamilton *et al.*, 2004). Emphasis has been placed on the use of selective toxicants, particularly *Bacillus thuringiensis*-based products, which have little or no adverse effect on key parasitoids (Verkerk and Wright, 1996; Abdel-Razek *et al.*, 2006), or spraying of insecticides only when predetermined thresholds have been reached (Chen and Su, 1986; Reddy and Guerrero, 2000).

At the Asian Vegetable Research and Development Centre (AVRDC), a successful integrated pest management programme had been developed to effectively control the diamondback moth by combining the use of the parasitoid *Diadegma semiclausum* and *Bacillus thuringiensis* (Talekar *et al.*, 1992; Talekar, 1992). Other methods include a combination of two or more of sprinkler systems, *C. plutellae*, granulosis virus and insecticides (Nakahara *et al.*, 1986; Andrews *et al.*, 1992; Loke *et al.*, 1992). A combination of yellow sticky traps for diamondback moth adults and action threshold for larvae had given good results in Thailand (Rushtapakornchai *et al.*, 1992; Hallett *et al.*, 1995). Reddy and Guerrero (2000) reported that an IPM programme based on the pheromone trap catch threshold of eight moths per trap per night, which included utilization of *C. plutellae*, (250 adults ha⁻¹), the predator *Chrysoperla carnea* (2500 eggs ha⁻¹), neem based chemical nimbecidine (625 ml ha⁻¹), *B. thuringiensis* (500 ml ha⁻¹) and the synthetic insecticide Phosalone (2.8 litre ha⁻¹) induced reduction of trap catches, egg and larval populations. It also led to economic savings of \$410 ha⁻¹ in 1997. In Ghana the advent of the IPM-Farmer Field Schools (IPM/FFS) programmes in 1999-2001 encouraged farmers to do Agro-

Ecosystem Analysis (AESAs) before applying any control measure. The AESA involved assessment of the health of the plant, the moisture content of the soil and the role of the different arthropods with special reference to the presence of natural enemies and, thus, made informed decisions (Youdeowei, 2002).

Muniappan and Marutani (1992) observed that in Guam, a combination of Dibrom 8 EC, natural enemies and insecticides can potentially give satisfactory control of crucifer pests. Wyman (1992) reported that the integration of biological control, cultural control, host plant resistance and other management techniques will play an increasingly important role in insecticide resistant management for all crucifer pests.

CHAPTER THREE

3.0 SEASONAL VARIATION OF PARASITOID-HOST ASSOCIATIONS AND EFFECT OF INSECTICIDES

3.1 Introduction

The most damaging insect pests of the common cabbage, *Brassica oleracea* var. *capitata* are the Lepidopterans: *Plutella xylostella*, *Pieris rapae*, *Trichoplusia ni* and *Hellula undalis* (Talekar, 1992; Anene and Dike, 1996; Dobson *et al.*, 2002; Hamilton *et al.*, 2004). The relative importance of these species varies from country to country or may even be seasonal (Harcourt *et al.*, 1955, Oatman, 1966; Bell and McGeoch, 1996; Liu *et al.*, 2000). However, *P. xylostella* is cosmopolitan and it is considered the most important pest worldwide causing production losses of up to 60% (Pratissoli *et al.*, 2008). For this reason, insecticides are frequently applied on cabbage in order to produce marketable heads. This practice has led to the development of multiple resistance to insecticides by *P. xylostella* (Ninsin, 1997; Abdel-Razek *et al.*, 2006).

In order to address this problem, the use of biological control agents and the development of integrated pest management programmes, are considered feasible options (Hill and Foster, 2000; Pratissoli *et al.*, 2008). Significant control by biological control agents had been reported in various countries (Liu *et al.*, 2000; Mahar *et al.*, 2004). Despite this recognition, very few studies have been done to assess the effect of commonly used insecticides and insect growth regulators on the natural enemies (Fan and Ho, 1971; Martinez-Castillo *et al.*, 2002). In Ghana, Ninsin (1997) observed that various synthetic insecticides applied on cabbage had adverse

effects on non-target insects and other beneficial organisms. Many pesticides are also known to be more toxic to consumers and natural enemies than to the pests (Wilkinson *et al.*, 1975; Schuster, 1994; Pratisoli *et al.*, 2008).

Mani and Krishnamoorthy (1984) observed that some insecticides had adverse effects both on the cocooned stages and adults of *C. plutellae* an important parasitoid of *P. xylostella* in parts of India. However, contradictory reports on the adverse effects of insecticides on *C. plutellae* have also been given by various authors. Ooi (1992), Kao and Tzeng (1992), Liu *et al.* (2000), Rowell *et al.* (2005) indicated that this species was either tolerant to or had achieved a certain level of resistance to insecticides in the field. In Ghana, little or nothing is known regarding the relative and seasonal importance of the Lepidopteran pests of cabbage, the identity of their parasitoids and the effect of commonly used insecticides on the parasitoids (Obeng-Ofori, 2000).

The objective of this study was to determine the seasonality of parasitoid-host associations on cabbage, levels of parasitism and the effect of the commonly used insecticides on the development of the major parasitoid.

3.2 Materials and Methods

3.2.1 The Experimental Site

The study was carried out on plots at the Weija Irrigation Company (WEICO) site at Tubaman near Weija in the Greater Accra region (Fig. 3.1) between 1996-1997 and 2000-2008. This site was chosen for four main reasons: The commercial production of cabbage and other vegetables including export crops that spans over 10 years (Annual Reports WEICO, 1999) with the consistent use of insecticides against the key

pests of cabbage. Besides, *Plutella xylostella* was known to be resistant to the common insecticides in use in that area (Annual Reports WEICO, 1999). Field surveys were also carried out to investigate the occurrence of the major pests and associated parasitoids in parts of the Greater Accra, Eastern, Volta, Western and Ashanti regions (Fig. 3.1).

The WEICO study site is located at latitude 5° 31' N and longitude 0° 21' W. It lies about 21 km west of the city of Accra on the road to Winneba, Cape Coast and Takoradi. It is about 4.2 km. from the said link road towards the sea (Atlantic Ocean) in the south. It is a generally windy area with average minimum and maximum temperatures of 23 °C and 31 °C, respectively. Relative humidity during the study period ranged from 31 - 62%, with an average of 44%.

3.2.2 Planting

Planting of the cabbage variety KK cross was done in the major and minor rainy seasons as well as the dry season.

The first season planting was done from April to July of 1996 to coincide with the major rainy season. Cabbage seeds were nursed for four weeks and transplanted in a RCBD on 2nd May. Prevailing temperatures at the experimental site ranged from 23 °C - 30 °C.

The second planting was done from August to December of 1996 and fell within the minor rainy season. Cabbage seeds were nursed and transplanted on 4th October in a RCBD. Prevailing temperatures at the site ranged from 23.5 °C - 31.5 °C.

The third planting was done in the dry season between January and April 1997. Transplanting of seedlings was done on 28th February after four weeks in the nursery in a RCBD. Prevailing temperatures ranged from 26 °C - 31 °C.

3.2.3 The Experimental Layout

The experiment consisted of four treatments arranged in a randomised complete block design (RCBD) with four replications. The experimental area of 38.64 m² was separated from other vegetable farms by approximately 100 meters. The land was ploughed and harrowed and then watered before the beds were raised using a hoe. Each bed was later leveled by raking and pieces of stone and other unwanted materials were removed before transplanting of cabbage seedlings. Each plot measured 4.2 by 2.3 meters. There were 3 rows per plot and each row had 7 plants, giving a total of 21 plants per plot. The distance between blocks was 1.5 m and between plots in a block was 1 m. Plant spacing was 60 cm within rows and 75 cm between rows.

3.2.4 Treatments Applied

The treatments applied were:

1. Lambda-Cyhalothrin formulated as Karate 2.5 E.C at the rate of 2.4 ml/ litre of water
2. 1.0 g *Bacillus thuringiensis* wettable powder (Dipel 2x)/ litre of water
3. 50 g neem (*Azadirachta indica*) seed powder/litre of water extract (applied only once)
4. Unsprayed Control (Water only)

Neem Seed Water Extract was prepared as follows:

Dried neem seeds were purchased and stored in jute sacks in an air-conditioned room with an average temperature of 23.0 ± 2 °C and relative humidity of $45 \pm 1.0\%$. Based on the concentration of 50 g/litre of water, 194.1 g. were weighed and ground using a Moulinex mill of capacity 95.1 cm^3 . The mill was, each time, filled to the brim and the seeds milled for about two minutes into fine powder. The powder was then mixed with the 3.9 litres of water and three spoonfuls of 'Omo' detergent was added to reduce the surface tension of the mixture. The mixture was kept overnight and then sieved through a fine plastic strainer to obtain the extract.

3.2.5 Fertiliser Application

The dose and timing of application of fertiliser recommended by Sinnadurai (1992) were followed. This involved a split application of 450 kg/ha of 15:15:15 NPK at seven days and twenty seven days after transplanting. A single dose of Sulphate of ammonia at 250 kg/ha was also applied at 34 days after transplanting. Basal applications of the fertilizer were done at a distance of 10 - 15 cm away from the plant at a depth of 5 - 6 cm. For each plant, 10 g. of the fertilizer was applied in the evenings as recommended.

3.2.6 Insecticide Application

The concentrations of the lambda cyhalothrin and *Bacillus thuringiensis* used were based on manufacturer's recommendations for field applications. For the neem seed water extract in addition to the recommended rates, a preliminary study was done to determine the concentration because of the varying potency effects of neem. The dosages tested were 25 g/l, 50 g/l and 75 g/l. The application rates in litres per

hectare required for the total land area of 38.64 m² for the experiment is shown in (Table 3.1). The neem seed water extract treatment was added during the minor rainy and dry seasons. This was because after the major rainy season study, it was observed that damage was high on the unsprayed plots and parasitoid activity was very low till about 5 weeks after transplanting. The additional neem treatment was, therefore, imposed to complement the effect of the parasitoids during the first four to five weeks before pest numbers built up to appreciable levels.

Table 3.1: Volumes of Insecticides Applied to Cabbage Plants

Insecticide	Fourth WAT Quantity/ha	Sixth WAT Quantity/ha	Eighth WAT Quantity/ha
Karate	4.66 l	7.45 l	9.32 l
<i>Bt</i>	1.94 kg.	3.11 kg.	3.88 kg.
NSWE	194.1 kg.	nil	nil

NSWE=Neem seed water extract

WAT= Week after transplanting

The insecticides were applied using a calibrated 15 - litre tank capacity knapsack sprayer (Cooper Pegler, U.K. Ltd.) fitted with a fine plastic hollow cone nozzle obtained from (Chemico Chemical Ltd., Ghana). Bionex was added to the spray solution as a spreader. Insecticide applications started on the fourth week after transplanting. This was done in the evenings after the first sampling and, thereafter, every two weeks, except for the neem treatment which was applied only once in the fourth week after transplanting. Separate spray equipment was used for each treatment to avoid contamination.

3.2.7 Incidence and Seasonal Abundance of Pests and Parasitoids

Sampling for insects on the experimental plots was started between eighteen and twenty days after transplanting when the first signs of insect attack on the leaves were observed and was done till harvest. Sampling was carried out once a week on the seven central plants in each of the treatment plots from 08 hours in the morning. During sampling, all developmental stages of insects on the five upper leaves as well as the two leaves surrounding the bud and the bud itself were carefully collected into petri dishes lined with filter paper and provided with a piece of cabbage leaf. Larvae which fell to the ground or spun a thread to escape were collected. On plants with multiple heads, the same head was tagged and sampled each time. All samples were labeled and taken to the laboratory for rearing until adult emergence of pest or parasitoid for subsequent identification and counting.

A replication of the experiment could not be done for another year because two cropping seasons were lost to the diamondback moth. In the year 2000 - 2001 a farmer's farm at the Weija Irrigation Company site was sampled for three cropping seasons. It was considered as a farmer's practice.

The farmer applied various insecticides such as Rimon (a Benzoylphenyl Urea), Lamda-Cyhalothrin (Karate), *Bacillus thuringiensis* (Biobit) and neem seed water extract on his plots. He applied insecticides from two weeks after transplanting or when in his opinion there were many insects. The cabbages were planted in long rows. Insects were sampled as described for the experimental plots.

3.2.8 Laboratory Rearing of Pests

The eggs, larvae and pupae of the pests collected in the field were kept separately in petri-dishes. The eggs still attached to cabbage leaves were placed on moist filter paper in petri dishes on the laboratory bench for incubation. The larvae were separated and each was placed on a piece of cabbage leaf on a wet filter paper in a petri dish. Each larva was transferred into a clean petri dish with a fresh piece of cabbage leaf daily and observed until it pupated or either parasitoid larvae or pupae emerged. Emerged pupae of pests were kept in petri dishes lined with dry filter paper till adult emergence. The insects that emerged were stored in 70% alcohol or mounted for identification. All the rearings were done at a temperature of 23 ± 2 °C and relative humidity of $45 \pm 1\%$.

3.2.9 Weekly Parasitism Trends by *Cotesia plutellae* and *Euplectrus laphygmae* in Relation to *Plutella xylostella* and *Trichoplusia ni*

All the parasitoid larvae, pupae and adults emerging from the field collected immature stages of pests from the seven central plants of all the treatments were recorded daily in the laboratory. Parasitoid larvae or pupae that emerged from hosts were each kept in separate glass tubes plugged with cotton wool until the adults emerged. The larvae and pupae of pests that did not develop into adults were dissected to determine whether they had been parasitized and numbers recorded. Parasitism was therefore determined from rearing of pests as well as from the dissections. The parasitoids that emerged from its host were recorded for each week's sample to determine parasitism and relationship between the parasitoids and the host till harvest of the cabbage. The parasitoids that emerged were stored in 70% alcohol or mounted for identification. All insects were maintained at a temperature of 23 ± 2 °C and relative humidity of 45

± 1%. Mean percentage parasitism was determined for all the treatments for comparison.

3.2.10 Identification of Pests and Parasitoids

The pests and parasitoids collected or observed were identified using the reference collections at the Entomology and Nematology Department of the University of Florida, USA. Specimens were also sent to CABI Bioscience, U.K. for confirmation and in some cases for the initial identification.

3.2.11 Emergence and Mortality of *Cotesia plutellae* Exposed to Insecticides

Emergence rates of *C. plutellae* adults were determined for all the parasitoid pupae that emerged from the pests collected from the seven central plants for all the treatments in the three seasons. In addition, all the pupae of *C. plutellae* were also collected from the seven central plants for all the treatments 3 weeks after transplanting during the major rainy season of May to July and the dry season from February to April on a single crop. Each pupa was kept in a separate glass tube and plugged with a piece of absorbent cotton wool till emergence of the adults in the laboratory at an average temperature of 23 ± 2 °C and RH of 45 ± 1 %. On emergence, each parasitoid adult was identified. Those that did not emerge after two weeks were kept for a further three weeks. Non-emergence after this period was considered to be mortality due to the insecticide. They were then dissected to determine their state of development and species where possible.

3.2.12 Laboratory Studies on Mortality of Adults and Emergence of Pupae of *C.*

***plutellae* Exposed to Different Insecticides**

A synthetic insecticide Lambda-Cyhalothrin marketed as Karate 2.5 EC, a biopesticide *Bacillus thuringiensis* as wettable powder and a commercial neem formulated product, Neemazal, were evaluated against the most abundant parasitoid *Cotesia plutellae*. All the tests were carried out in the laboratory with a mean temperature of 28 ± 2 °C and relative humidity of $55 \pm 1\%$. Two parameters (direct mortality to adults and non-emergence from pupae) were used to determine the effect of the insecticides (Gaitonde, 1978).

Two methods of application were used to determine the residual effect and toxicity of the three insecticides to the pupae and adults of *C. plutellae*. These were the filter paper and direct contact application methods, respectively (Gaitonde, 1978). Concentrations of insecticides used were 2.4 ml. Karate/litre of water, 1.0 g *Bacillus thuringiensis* wettable powder/ litre of water, 1.0 ml. Neemazal/litre of water and water only as control.

3.2.12.1 Filter Paper Method

A strip of filter paper measuring 11 cm in diameter was cut into two and one half dipped into the insecticide solution, air dried for 20 minutes and placed in a transparent jar measuring 12 cm deep and 9.5 cm in diameter as described by Wilkinson *et al.* (1975). The jar was covered with nylon mesh secured with a rubber band. Ten day - old adults of *C. plutellae* were introduced into the set up through a slit made in the mesh which was subsequently plugged with a cotton wool. The parasitoids were held in the jar for six hours. A piece of cotton wool soaked in 10%

honey solution was provided as food through a slit made in the side of the jar. After six hours, the parasitoids were transferred into a clean jar containing a piece of cotton wool soaked with 10% honey solution and observed for a further 48 hours. A control was set up with the other half of the filter paper soaked with water. Adult mortality was recorded at the end of the 6-hour exposure period, 24 hours and 48 hours after treatment (Gaitonde, 1978). Each treatment was replicated four times and each replicate had 10 adults of *C. plutellae*

3.2.12.2 Direct Application Method

For the direct contact insecticide application, two methods were used to determine the direct effect of contact application of the test insecticides on the adult parasitoids. In the first method, a piece of cabbage leaf with the same dimensions as the filter paper described above was dipped once in each treatment. This was done to simulate natural conditions in the field as much as possible. The treated leaf was immediately placed in a transparent jar and 10 one-day old adults of *C. plutellae* were introduced and provided with food as described above. The parasitoids were transferred after six hours and mortality recorded after 48 hours following the same procedure described above.

For the second method, adult parasitoids were introduced into a jar immediately after one puff of the insecticide solution had been sprayed into it from an Atomiser. The same procedure, with regard to feeding and recording mortality described above was followed. A control was set up using water in place of the insecticide solution. Each treatment was replicated four times.

A similar experiment was carried out using the pupae of *C. plutellae*. Each of the treatments was replicated four times and each replicate had 10 pupae. The filter paper and cabbage leaf procedures described above were followed for the pupae of *C. plutellae*. For the spray method, 10 day - old pupae were placed uniformly on a glass plate and sprayed quickly with one puff of the insecticide from an Atomiser filled with 2 ml of the insecticide solution.

For the direct contact application method, the pupae were left to air-dry on the laboratory bench for 20 minutes after the 6 hour insecticide exposure period. After that each pupa was transferred into a clean separate specimen tube which was then plugged with cotton wool and left to stand in trays on the laboratory bench till adult emergence. For the control experiment, pupae were treated with water. Failure of pupae to emerge was taken as mortality due to the effect of the treatment. Pupae which failed to emerge were kept and observed for a further three weeks after which they were dissected to determine their state of development (Day, 1994).

3.2.13 Statistical Analysis

All mortality data were corrected for natural mortality using Abbot's formula (Abbot, 1925). All percentages were transformed using arcsine transformation and counts transformed using natural log prior to Analysis of Variance. Mean separation was done using Duncan's Multiple Range Test (DMRT). Pearson's correlation was used to determine the relationship between populations of *P. xylostella* and its parasitoid. All the analyses were done with the Statistical Programme for the Social Sciences (SPSS) version 16 software.

3.3 Results

3.3.1 Incidence and Seasonal Abundance of Lepidopteran Pests

Larvae and pupae of six species of Lepidoptera were recorded on cabbage in all the three seasons at the Weija site. Five of the species were pests that fed directly on the plant and caused damage. These were the diamondback moth, *Plutella xylostella*, the cabbage looper, *Trichoplusia ni*, the cabbage webworm, *Hellula undalis*, the leaf worm *Spodoptera littoralis* and the African bollworm, *Helicoverpa armigera*. The distribution map of the pests recorded in this study is shown in Figure 3.1.

The sixth species, the beet webworm, *Spoladea recurvalis* was occasionally found on cabbage, but was usually associated with the weed *Cyperus rotundus* (nut grass). Single specimens of *Spodoptera triturrata* (Walker) were collected twice on cabbage at the experimental site during the minor rainy season. It was also collected once at the University of Ghana farms on Legon campus during the minor rainy season whilst the cutworm, *Agrotis sp* was recorded at Denche in the Western Region during a field survey.

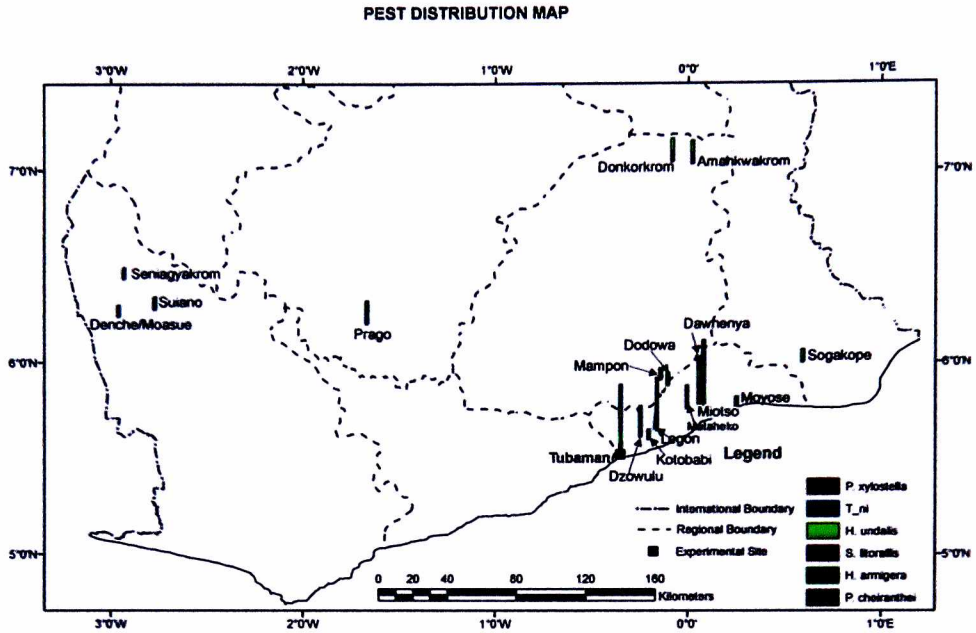


Figure 3.1: Distribution Map of Pests of Cabbage in Southern Ghana

In vegetable growing areas (Fig.3.1 and Appendix 3.1) where farmers were encouraged to diversify under the Agro-skills Development and Farmer Field Schools Programme of the FAO/UNDP Poverty Reduction Programme of 1999-2001, the diamondback moth was not observed. The cabbage flea beetle, *Phyllothreta cheiranthae* Weise, and *Hellula undalis* were present in the nursery and transplanted cabbage. Subsequent surveys in 2005 in Dodowa and Moyose in the Greater Accra region showed that the diamondback moth was still not present. The diamondback moth was also not recorded on cabbage in villages within the Homasi concession of AngloGold Ashanti (Ghana) Ltd. near Obuasi Mines in the Ashanti region where peasant farmers were introduced to the cultivation of cabbage in a vegetable diversification programme (Darpaah, 2008).

In general, it was observed that the abundance of pests at the experimental site was dependent on the prevailing season. In all seasons damage was observed three weeks after transplanting. The relative percentage abundance of pest species from the unsprayed plots for the three seasons is shown in Table 3.2. *P. xylostella* was most abundant in the dry season (69.6%) while *Trichoplusia ni* was most abundant in the major rainy season (79%). However, *S. littoralis* was most dominant in the minor rainy season, constituting 59% of the pest population. *Helicoverpa armigera* and *H. undalis* occurred in significant numbers during the dry season, but were both absent during the major rainy season.

Table 3.2 Relative Abundance of Larvae of Lepidopteran Pests of Cabbage in the Three Cropping Seasons on the Unsprayed Plots at the Experimental Site, Weija.

Percentage Abundance							
Season	Total No. of larvae	<i>P. xylostella</i>	<i>T. ni</i>	<i>S. littoralis</i>	<i>H. armigera</i>	<i>H. undalis</i>	<i>S. recurvalis</i>
Major Rainy	329	20.4 ^c	79.0 ^a	0.6 ^c	0.0 ^b	0.0 ^b	0.0 ^b
Minor Rainy	227	30.4 ^b	9.3 ^b	59.0 ^a	0.4 ^b	0.9 ^b	0.0 ^b
Dry	296	69.6 ^a	11.5 ^b	5.4 ^b	7.1 ^a	3.4 ^a	3.0 ^a
TOTAL	852	40.0	37.0	17.9	2.6	1.4	1.1

Means in the same column with same letters as superscripts are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

On the farmer's farm, where various insecticides were applied, *Plutella xylostella* formed 88.8% of the total pests and *T. ni* formed 5.3% in an annual production of cabbage (Table 3.3). *Plutella xylostella* was significantly most abundant during the minor rainy season and *T. ni* occurred in significant numbers during the major rainy season. *Hellula undalis* populations were highest in the dry season and least in the minor rainy season. *H. armigera* was most abundant during the dry season.

Table 3.3: Relative Abundance of Larvae of Lepidopteran Pests of Cabbage in the Three Cropping Seasons on Farmer's Plots at Weija.

Season	Total No. of larvae	Percentage Abundance					
		<i>P. xylostella</i>	<i>T. ni</i>	<i>S. littoralis</i>	<i>H. armigera</i>	<i>H. undalis</i>	<i>S. recurvalis</i>
Major Rainy	144	45.1 ^b	36.1 ^a	06.3 ^b	02.1 ^b	09.0 ^b	1.4 ^a
Minor Rainy	958	97.1 ^a	00.6 ^c	00.9 ^c	00.1 ^b	01.0 ^c	0.1 ^a
Dry	69	47.8 ^b	05.8 ^b	10.1 ^a	18.8 ^a	17.4 ^a	0.0 ^a
TOTAL	1171	88.8	05.3	02.1	01.5	02.0	0.3

Means in the same column with same letters as superscripts are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.2 Comparative Abundance of Larvae of Lepidopteran Pests on Unsprayed Experimental Plots and on Farmer's Plots at Weija

On both experimental plots and farmer's plots, *Plutella xylostella* was the most abundant during the study. There was a significantly higher number of *P. xylostella* larvae on the farmer's plots compared with the experimental plots ($p < 0.05$) (Table

3.4). Conversely, *Trichoplusia ni* and *S. littoralis* were significantly more abundant on the experimental plots.

Table 3.4: Comparative Percentage Abundance of Lepidopteran Pests on Experimental Plots and on Farmer's Plots

Plot	Total No. of larvae	<i>P. xylostella</i>	<i>T. ni</i>	<i>S. littoralis</i>	<i>H. armigera</i>	<i>H. undalis</i>	<i>S. recurvalis</i>
Experimental Plots	852b	40.0 ^b	37.0 ^a	17.9 ^a	2.6 ^a	1.4 ^a	1.1 ^a
Farmer's Plots	1171a	88.8 ^a	5.3 ^b	2.1 ^b	1.5 ^a	2.0 ^a	0.3 ^a

Means in the same column with same letters as superscripts are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.3 Population Density of Larvae of *P. xylostella*, *T. ni* and *S. littoralis* on Cabbage in the Three Seasons on Experimental Plots

The population density of *P. xylostella* was highest in the dry season. A significantly high mean density of 0.29 ± 0.05 larvae per plant ($p < 0.05$) (Table 3.5) was recorded during this season compared with the other pests. The least was observed during the major rainy season. There were many instances where several larvae of the diamondback moth were observed drowned in water that had collected on cabbage leaves after rains. However, it was the only species that occurred in significant numbers for all the seasons. On the other hand, a significantly high mean density of 0.60 ± 0.11 larvae per plant ($p < 0.05$) of *T. ni* was recorded in the major rainy season compared with the other seasons (Table 3.5). With regard to *S. littoralis*, a significantly high mean density of 0.39 ± 0.10 larvae per plant ($p < 0.05$) was recorded in the minor rainy season compared with the other seasons.

Table 3.5 Population Density per Plant of Larvae of *P. xylostella*, *T. ni* and *S. littoralis* on Cabbage in the Three Seasons

Pest	Major Rainy Season	Minor Rainy Season	Dry Season
<i>S. littoralis</i>	0.003 ± 0.003 ^{a*}	0.39 ± 0.10 ^{a**}	0.05 ± 0.02 ^{a*}
<i>P. xylostella</i>	0.15 ± 0.04 ^{a*}	0.20 ± 0.07 ^{ab*}	0.29 ± 0.05 ^{b*}
<i>T. ni</i>	0.60 ± 0.11 ^{b**}	0.06 ± 0.03 ^{b*}	0.09 ± 0.02 ^{a*}

Means in the same column with same letters as superscripts are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

*Means in the same row with same number of asterisk are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.4 Incidence and Seasonal Abundance of the Parasitoids

A total of 15 species of parasitoids, some of which also acted as hyperparasitoids were reared from the Lepidopteran pests at the experimental site (Table 3.6). *Cotesia plutellae* was the most important parasitoid of the major pest *P. xylostella* as well as *T. ni*, and was present throughout the year whenever cabbage was grown. *Euplectrus laphygmae* (Ferriere) was recorded in the major rainy season and minor rainy season and parasitized third instar larvae *T. ni*. None was collected in the dry season (February - March) when the incidence of *T. ni* was extremely low. It also parasitized *S. littoralis* on four occasions during the minor rainy season. The parasitoids *C. curvimaculatus*, *Notanisomorphella* sp and the two Tachinid species were specific to *S. littoralis* and they each parasitized this species only on two occasions during the minor rainy season and dry season. Only a single *H. undalis* was parasitized by *C. plutellae*. No parasitism of *H. armigera* was recorded and no egg parasitoids were observed from any of the pests during the study period.

Table 3.6 Seasonal Occurrence of Parasitoid/Hyperparasitoid Species and Lepidopteran Host Species on Cabbage at the Experimental Site

Parasitoids/ Hyperparasitoids	Host species	Seasonality of Parasitoid
Ichneumonidea		
<i>Cotesia plutellae</i>	<i>P. xylostella</i> and <i>T. ni</i> larvae	All 3 seasons
<i>Chelonus curvimaculatus</i>	<i>S. littoralis</i> larvae	MiRS
<i>Charops</i> sp.	<i>T. ni</i> & <i>S. littoralis</i> larvae	MiRS & DrS
Chalcidoidea		
<i>Brachymeria</i> sp.	<i>T. ni</i> larva via <i>Charops</i> sp	MiRS & DrS
<i>Hockeria</i> sp.	<i>P. xylostella</i> larvae	MiRS
<i>Elasmus</i> sp.	<i>P. xylostella</i> larvae via <i>C. plutellae</i>	DrS
<i>Euplectrus laphygmae</i>	<i>T. ni.</i> & <i>S. littoralis</i> larvae	MaRS&MiRS
<i>Notanisomorphella</i> sp.	<i>S. littoralis</i> larva	DrS
<i>Oomyzus sokolowskii</i>	<i>P. xylostella</i> larvae via <i>C. plutellae</i> <i>P. xylostella</i> larva-pupa	MaRS
<i>Tetrastichus atriclavus</i> S.L	<i>T. ni</i> larvae via <i>C. plutellae</i>	MaRS
<i>Pediobius</i> sp.	<i>P. xylostella</i> larvae & pupae	MaRS
<i>Trichomalopsis</i> sp.	<i>P. xylostella</i> larvae via <i>C. plutellae</i> <i>T. ni</i> larvae via <i>C. plutellae</i>	MaRS MaRS
Ceraphronoidea		
<i>Aphanogmus reticulatus</i>	<i>P. xylostella</i> pupae via <i>C. plutellae</i> <i>T. ni</i> larvae via <i>C. plutellae</i>	MaRS
Tachinidae		
<i>Blepharella</i> sp near <i>vasta</i>	<i>S. littoralis</i> larval-pupal	MiRS
<i>Peribaea orbata</i>	<i>S. littoralis</i> larva	MiRS

MaRS = Major rainy season MiRS = Minor rainy season DrS= Dry season
via *C. plutellae* means Parasitism of *C. plutellae* occurred inside *P. xylostella*.

Elsewhere in Ghana, *C. plutellae* was recorded in parts of the Greater Accra Region at the Kotobabi-Plant Pool (Accra), La Bawaleshi near Legon, Miotso near Dodowa, Dawhenya, and at Mampong in the Eastern region. The facultative hyperparasitoid *O. sokolowskii* was recorded in Dawhenya.

Cotesia plutellae was the dominant and most important parasitoid observed. Seven hundred and six (706) parasitoids were recorded from *P. xylostella* in the three seasons and 92% were *C. plutellae*. The rest (8%) comprised of facultative hyperparasitoids; *O. sokolowskii*, *Aphanogmus reticulatus*, *Trichomalopsis* sp. *Elasmus* sp. and two primary parasitoids *Pediobius* sp. and *Hockeria* sp. Thus, the primary parasitoid *C. plutellae* was attacked by 4 parasitoids. In the major rainy season when *T. ni* was more abundant than *P. xylostella*, of the 110 parasitoids observed from the former, 60.9% and 35.5% consisted of *C. plutellae* and *E. laphygmae* respectively. The remaining included the hyperparasitoids *Trichomalopsis* sp. *A. reticulatus* and *Tetrastichus atriclavus*. Only 12 out of the 152 *S. littoralis* larvae were parasitized by the five species of parasitoids recorded from it during the whole study period at the experimental site.

Cotesia plutellae and *Oomyzus sokolowskii* were the only primary parasitoid and facultative hyperparasitoid respectively, observed on the farmer's farm. *Cotesia plutellae* parasitized 1% of the total diamondback moth larvae of 1,040 (88.8%) sampled. The parasitoids were observed during the major rainy season in May. Out of the twelve diamondback moth larvae parasitized by *C. plutellae*, 42% were hyperparasitised by *O. sokolowskii*.

Based on the parasitoids and hyperparasitoids of *P. xylostella* and *T. ni*, the trophic relationships among species on cabbage is presented in figure 3.2.

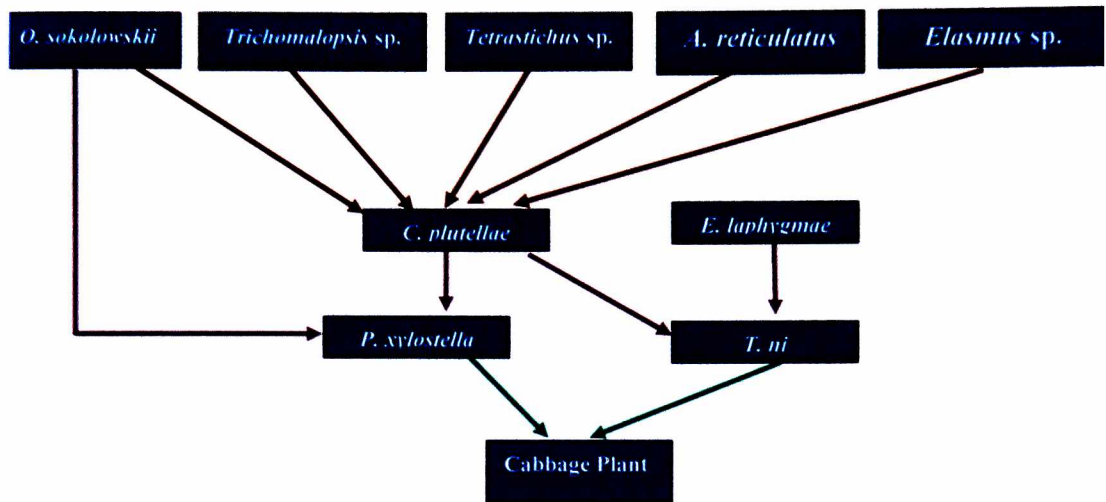


Figure 3.2: Trophic Relationships among *P. xylostella*, *T. ni* and Parasitoids and Hyperparasitoids on Cabbage.

3.3.5 Weekly Parasitism Trends by *C. plutellae* in Relation to *P. xylostella*

Population build up of *C. plutellae* in relation to its host the diamondback moth during cabbage production on the unsprayed plots was a density dependent relationship where an increase in diamondback numbers resulted in a corresponding increase in parasitism (Figs. 3.3 - 3.5). The results indicated that there was a distinct time lag of one to two weeks in the major rainy and minor rainy seasons (Figs. 3.3 and 3.4) after which parasitism became closely synchronized with host numbers from 25 DAT in the former season.

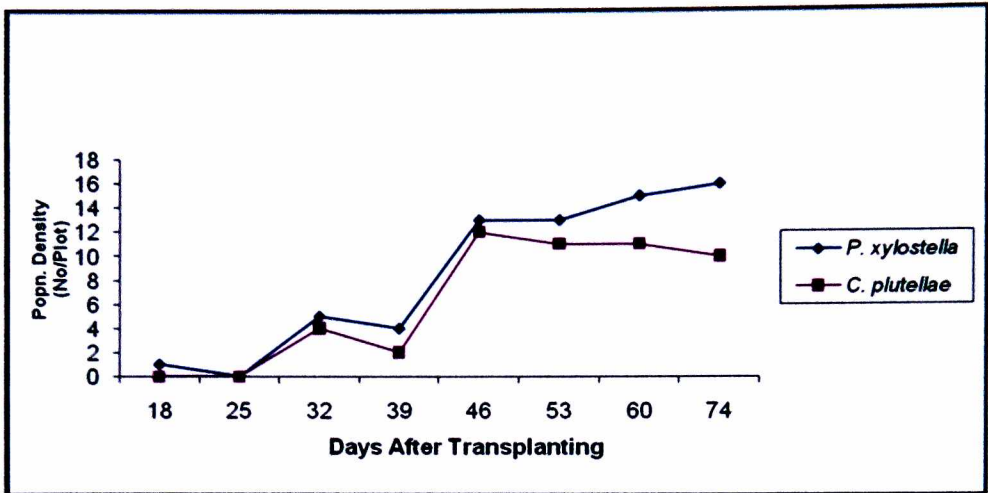


Figure 3.3: Weekly Parasitism Trends by *C. plutellae* in Relation to *P. xylostella* in the Major Rainy Season. Coefficient of Correlation $r = 0.97$

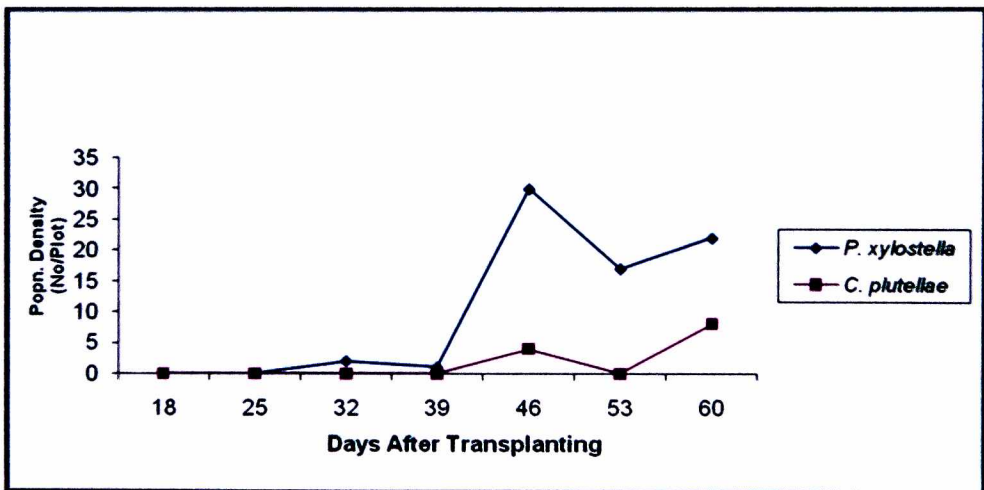


Figure 3.4: Weekly Parasitism Trends by *C. plutellae* in Relation to *P. xylostella* in the Minor Rainy Season. Coefficient of Correlation $r = 0.55$

In the dry season when build up of the pest was highest, there was no time lag between host numbers and parasitism (Fig. 3.5) and parasitism rates also increased as diamondback numbers increased.

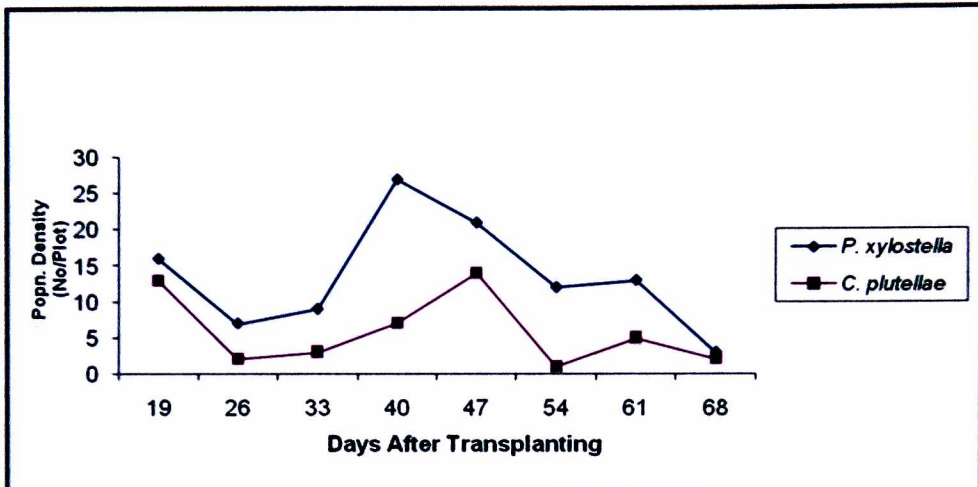


Figure 3.5: Weekly Parasitism Trends by *C. plutellae* in Relation to *P. xylostella* in the Dry Season. Coefficient of Correlation $r = 0.66$

The association between diamondback numbers and parasitism varied among the seasons and was strongest in the major rainy season. The Correlation coefficient, r between diamondback numbers and numbers parasitized during the major rainy season was $r = 0.97$ whilst in the minor season $r = 0.55$. In the dry season the Correlation coefficient $r = 0.66$. The Coefficient of determination, R^2 which is defined as the variation in parasitism that is dependent on the variation in diamondback numbers was $R^2 = r^2 = 0.970921^2 = 0.9427 = 94.3\%$ in the major rainy season. Hence, 94.3% of the variation in parasitism was due to the variation in host numbers. In the minor rainy season, 30.8% of the variation in parasitism was due to the variation in diamondback moth numbers whilst in the dry season it was 44.0%. It was very common to find many cocoons of *C. plutellae* scattered on the leaves at

harvest of the cabbage in the major rainy and dry seasons. The overall Correlation Coefficient r , between the diamondback numbers and *C. plutellae* was 0.51. The Coefficient of determination $R^2 = 0.262$. Hence, in an annual production of cabbage 26.2% of the variation in parasitism is due to the variation in the number of the diamondback moth.

3.3.6 Weekly Parasitism Trends by *C. plutellae* and *E. laphygmae* in Relation to *T. ni*

The relationship between the parasitoids *C. plutellae* and *E. laphygmae* and their host *T. ni*, was considered only for the major rainy season because no parasitism was observed during the minor rainy season and the population of the pest during the dry season was so low that any meaningful comparison was not possible. There was one week time lag after which the two parasitoids generally acted in a density dependent manner and the population started to build up around 25 DAT (Fig 3.6).

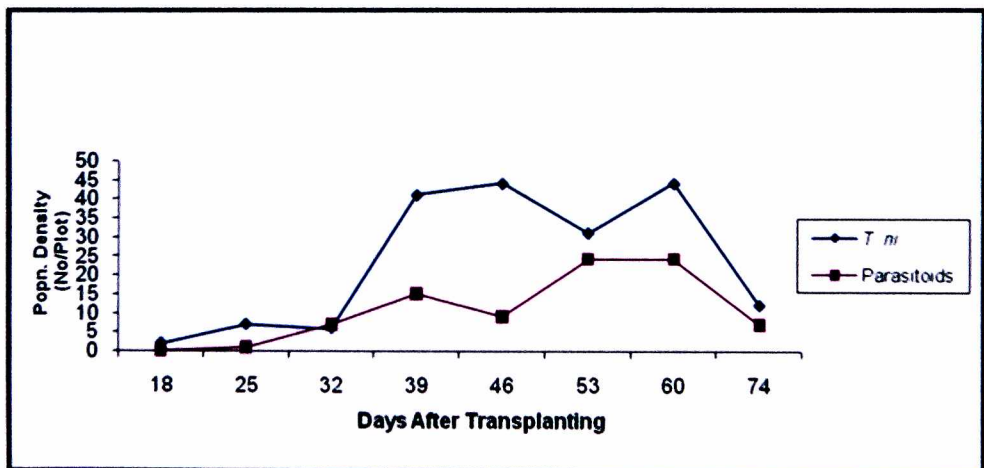


Figure 3.6: Weekly Parasitism Trends by *C. plutellae* and *E. laphygmae* in Relation to *T. ni* in the Major Rainy Season

3.3.7 Parasitism of *P. xylostella* by *C. plutellae* in Three Seasons

Wide seasonal variations were observed in the rates of parasitism. Mean percentage parasitism of *P. xylostella* by *C. plutellae* was highest ($p < 0.05$) during the major rainy season ($68.6\% \pm 12.9$) and least during the minor rainy season ($9.9\% \pm 7.1$). There was no significant difference ($p > 0.05$) in the rates of parasitism between the major rainy season and the dry season (Figure 3.7).

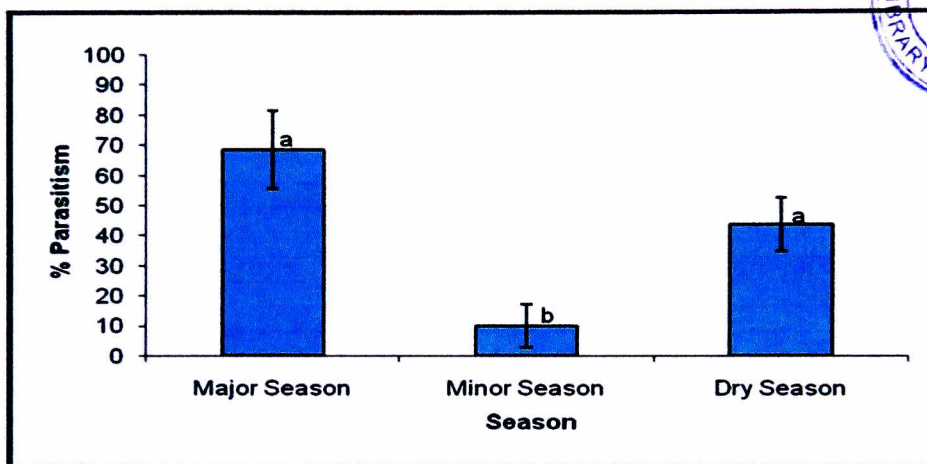


Figure 3.7: Seasonal Variation in Mean Percentage Parasitism of *P. xylostella* by *C. plutellae*

Bars with same alphabets are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.8 Parasitism of *P. xylostella* by *C. plutellae* on Insecticide Treated Plots

Parasitism of larvae of *P. xylostella* was substantial despite the insecticide pressure imposed. Parasitism rates were higher on the Karate treated plots but these were not significantly different ($p > 0.05$) from the unsprayed, *Bt.* and neem seed water extract (NSWE) treated plots for all three seasons (Table 3.7).

Table 3.7 Mean Percentage Parasitism of *P. xylostella* by *C. plutellae* on Different Treatments in the Three Seasons

Treatment	% Parasitism		
	Major Rainy Season	Minor Rainy Season	Dry Season
Unsprayed	68.6 ± 12.9a*	9.9 ± 7.1a**	43.7 ± 8.9a*
<i>Bt</i>	78.3 ± 12.1a	-	60.6 ± 4.2a
Karate	81.3 ± 4.1a	11.1 ± 6.6a	61.3 ± 4.1a
NSWE	-	3.3 ± 3.3a	50.3 ± 8.8a

Means with the same letters in the same columns are not significantly different at the 5% confidence level. Duncan's Multiple Range Test.

*Means in the same row with different number of asterisks as superscripts are significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.9 Parasitism of *T. ni* by *C. plutellae* and *E. laphygmae* in the Major Rainy Season

Mean percentage parasitism of *T. ni* by *C. plutellae* and *E. laphygmae* during the major rainy season was 29.4% ± 7.5.

3.3.10 Parasitism of *T. ni* by *C. plutellae* and *E. laphygmae* on Insecticide Treated Plots

There was no significant difference ($P > 0.05$) in parasitism of *T. ni* by *C. plutellae* and *E. laphygmae* irrespective of treatments (Table 3.8).

Table 3.8 Mean Percentage Parasitism of *T. ni* by *C. plutellae* and *E. laphygmae* on Different Treatments in the Major Rainy Season

Treatment	%Parasitism
Unsprayed	29.4 ± 7.5a
<i>Bt</i>	36.7 ± 9.4a
Karate	41.7 ± 20.1a

Means with the same letters in a column are not significantly different at the 5% confidence level, (Duncan's Multiple Range Test).

3.3.11 Emergence of *C. plutellae* Adults from Field Parasitised Pests

The proportion of *C. plutellae* adults that emerged from field parasitized *P. xylostella* was not significantly different ($p > 0.05$) between unsprayed and Karate treated plots in all seasons (Table 3.9). In the major rainy season the highest mean percentage adult parasitoid emergence was recorded from hosts collected from *Bt* treated plots. The single *P. xylostella* larva collected from the neem treated plots in the dry season emerged, hence, the 100% emergence of parasitoid adults.

Table 3.9 Emergence of *C. plutellae* Adults Reared from Field Parasitized *P. xylostella* from the Different Treatments in the Three Seasons

Season	Unsprayed	Karate	<i>Bt</i>	Neem
Major rainy season	79.17 ± 10.63 ^{a*}	71.64 ± 10.39 ^{a*}	100 ± 0.00 ^{b*}	-
Minor rainy season	75.00 ± 25.00 ^{a*}	53.35 ± 18.84 ^{a*}	-	100 ± 0.00 ^a
Dry season	80.18 ± 10.49 ^{a*}	65.69 ± 6.80 ^{a*}	70.91 ± 11.25 ^{a**}	64.57 ± 6.04 ^a

Means in the same row with same letters as superscripts are not significantly different at 5% confidence level (Duncan's Multiple Range Test).

*Means in the same column with different number of asterisks as superscripts are significantly different at 5% confidence level (Duncan's Multiple Range Test). Where there is no asterisk, data was not included in analysis.

It was also observed that it was only *C. plutellae* adults recorded from the diamondback moth collected from Karate treated plots that died in the process of eclosion (could not push the cap of the pupal case), or died the same day, lived for only a day or were malformed (twisted wings or twisted abdomens).

With regard to *T. ni* the highest proportion of adult parasitoids emerged from pest samples collected from *Bt*. treated plots (100%) and unsprayed plots (85.70 ± 6.33) and the least (53.96 ± 29.14) from samples collected on Karate treated plots (Figure 3.8).

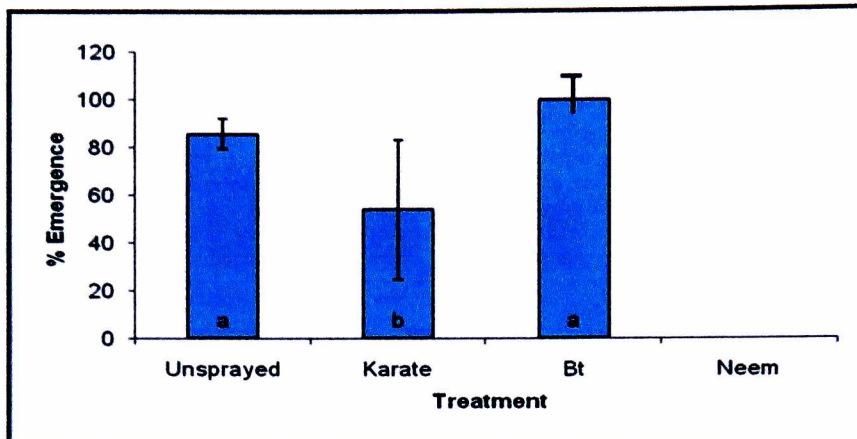


Figure 3.8: Emergence of both *C. plutellae* and *E. laphygmae* Adults from Field Parasitized *T. ni* from the Different Treatments in the Major Rainy Season. Bars with the same letters are not significantly different at the 5% confidence level (Duncan's Multiple Range Test).

3.3.12 Emergence of *C. plutellae* Adults Collected as Pupae Exposed to Different Insecticides in the Field

Seasonal differences were observed in the abundance and adult emergence from parasitoid pupae collected in the field (Figure 3.9 and Appendix 3.2). The highest total numbers of parasitoid pupae were collected from the Karate treated plots in both seasons. Percentage emergence of parasitoids was significantly higher ($p > 0.05$) in the major rainy season samples than the dry season samples in all treatments (Figure 3.9). In the major rainy season, there was no significant difference ($p > 0.05$) between the rates of adult emergence of parasitoid pupae collected on Karate treated plots and the unsprayed plots. There was also no significant difference ($p > 0.05$) between the rates of emergence from samples collected from the *Bt* and unsprayed plots (Figure 3.9). In the dry season, the rate of emergence in samples collected from all treatments was similar.

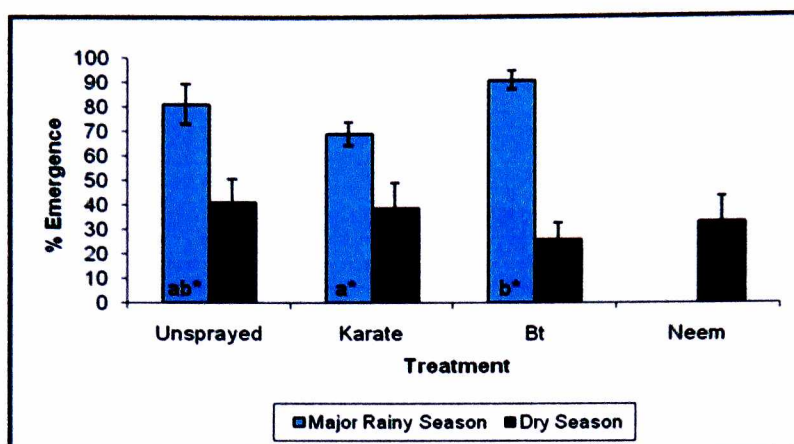
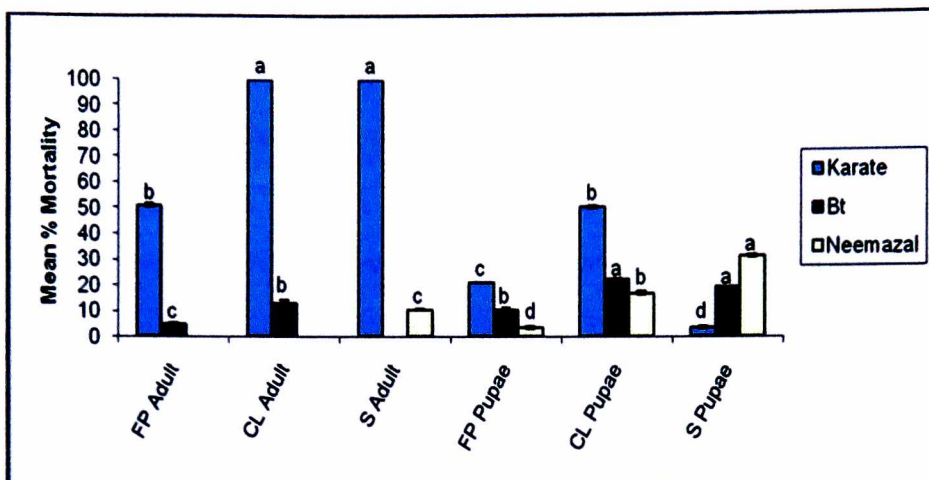


Figure 3.9: Percentage Emergence of *C. pluteae* Adults Collected as Pupae from the Different Treatments.

Bars of the same colour with different letters are significantly different at 5% confidence level (Duncan's Multiple Range Test). Component bars with different number of asterisks are significantly different at 5% confidence level (Student's t-Test).

3.3.13 Mortality of *C. pluteae* Adults and Emergence of Pupae Exposed to Insecticides in the Laboratory.

The test insecticides differed with respect to the mortality caused to adults and pupae of *C. pluteae* (Figure 3.10). Generally, mortality was higher in the adult parasitoids than in the pupae. Of the insecticides tested, Karate had the most adverse effect on adults of *C. pluteae* irrespective of application method. It resulted in 100% mortality of *C. pluteae* within ten seconds of direct exposure.



Key: FP= Filter paper CL=Cabbage leaf dip S = Spray

Figure 3.10: Mortality of Adults and Pupae of *C. plutellae* Exposed to Different Insecticides.

Bars of the same colour with different letter are significantly different at the 5% confidence level (Duncan's Multiple Range Test).

Neemazal had the least adverse effect on the adults after 48 hours. *Bt.* at 1.0 g/litre and Neemazal at 1% caused a significantly higher mortality in the pupae than in the adults. The application methods of the insecticides had variable effects on both the adults and pupae of the parasitoid. A significantly higher mortality of 31% ($p < 0.05$) was recorded in the pupae exposed directly to Neem Azal as spray whereas Karate caused only 3.6% after 48 hours.

3.4 Discussion

The Lepidopteran species found on cabbage in Ghana were similar to species recorded in some countries (Talekar, 1992; Anene and Dike, 1996; Dobson *et al.*, 2002). However, other pests such as *Pieris rapae* (Linnaeus) (Oatman and Platner, 1969) and *Crociodolomia binotalis* (Zeller) (Sastrosiswojo and Setiawati, 1992)

recorded elsewhere in South East Asia were not observed in the present study. Forsyth (1966) however, reported *C. binotalis* on cabbage in Aburi and Tafo both in the Eastern region of Ghana.

Plutella xylostella is considered as a serious pest worldwide and occurs in significant numbers in parts of South East Asia (Talekar, 1992) but in France, Germany and South Africa it is ranked substantially low (Lim, 1986; Mosiane, *et al.*, 2003). Results of this study have shown that it occurred in abundance on cabbage in areas where the crop had been traditionally grown for at least 10 years in Ghana. However, contrary to reports by Tadashi *et al.* (1986), Walunj and Pawar (2004) and (Pratissoli) *et al.* (2008) that *P. xylostella* occurs wherever cabbage is grown, the field surveys carried out during this study, showed that the pest had not yet invaded some areas in the Greater Accra region where farmers were introduced to grow cabbage for the first time under the Agro-skills Development and Farmer Field Schools Programme of the FAO/UNDP National Poverty Reduction Programme in (1999 - 2001). In these areas where cabbage had been recently introduced, the cabbage flea beetle, *Phyllotreta cheiranthi* and *Hellula undalis* were present. *Plutella xylostella* was also not present in villages located near the Homasi concession of AngloGold Ashanti Ghana Ltd. in the Amansie Central District in the Ashanti Region.

Spoladea recurvalis is not considered a pest of cabbage as it was more associated with the weed, *Cyperus rotundus*. Its population was only 1.1% of the total Lepidoptera pests in an annual production of cabbage at the experimental site and may have moved onto the crop from the weeds. Adults were usually observed resting on weeds rather than on the cabbage.

This study has demonstrated, for the first time, the seasonality of the major Lepidopteran pests in Ghana. *Trichoplusia ni* was more abundant than *P. xylostella* in the major rainy season but the latter was present in significant numbers throughout the year and may therefore, cause more damage in an annual production of three seasons. *Plutella xylostella* consumes more foliage than *T. ni* in an annual production of cabbage despite the voracious feeding habit of *T. ni* (Harcourt *et al.*, 1955; Capinera, 1999). It overshadows *T. ni* because of its ability to quickly develop resistance to virtually all insecticides used to control it (Hill and Foster, 2000). It is the most important of the crucifer pests and causes severe economic damage to cabbage (Sarfray *et al.*; 2005). The continuous presence of this pest on the same plants that were sampled weekly throughout the study period also suggests that there may be as many as 20 generations per year. Keinmeesuke *et al.* (1992) and Abdel-Razek *et al.* (2006) reckoned that as many as 20 - 25 generations can occur in a year in the tropics. There were several instances when whole crops were lost to *Plutella xylostella* at the experimental site and farmers had to prematurely harvest their cabbage or abandon their farms because of the pest (Cobblah, 2000). Attention must be paid to *Trichoplusia ni* during the major rainy season, having constituted 79% of the total pest population during the period of this study. This would be in agreement with observation by Anene and Dike (1996) who observed that in Nigeria, the population of *T. ni* can reach epidemic levels. *Hellula undalis* constituted only 1.4% of the total pests, and was only present during the minor rainy season and dry season. The pest is known to cause extensive damage to cabbage seedlings in the nursery as well as young plants in the field (Muniappan and Marutani, 1992; Jayma and Ronald, 2007). It has been reported as a major pest of cabbage in Ghana (Obeng-Ofori *et al.*, 2007). *Spodoptera littoralis* has not been recorded on cabbage in Ghana before and may be

considered seasonal as it occurred in significant numbers only in the minor rainy season during the study. *Helicoverpa armigera* accounted for 2.6% of the pest population throughout the study. Various *Spodoptera* species, as well as *Helicoverpa armigera* are considered occasional or seasonal pests on cabbage in various countries (Boling and Pitre, 1971; Waterhouse, 1992; Poelking, 1992; Berg and Cock, 2000).

Findings from the present study also indicate that the incidence and importance of a particular species and, its seasonal trends may vary from place to place and with time of planting as observed by Dennill and Pretorius (1995) and Mosiane *et al.* (2003). Ooi (1986) and Alam (1992) noted that dry season or warm weather favours the build-up of *P. xylostella*. This observation has been confirmed in the present study with the populations of *P. xylostella* significantly higher during the dry season than in the major rainy season when *T. ni* was more abundant. Conversely, Nagarkatti and Jayanth (1982) observed a significantly higher build-up of *P. xylostella* during the rainy season compared with other seasons.

Of the fifteen species of parasitoids and hyperparasitoids recorded from the pests, *Cotesia plutellae* was the most dominant parasitoid and was active in all the three seasons at the experimental site. It accounted for over 90% parasitism of the diamondback moth as have been observed in parts of China by Liu *et al.* (2000) and in South Africa by Mosiane *et al.* (2003). It comprised 60.9% of parasitism of *T. ni*. Apart from *C. plutellae*, about 30 species of Chalcidoidea have been recorded in the literature as primary parasitoids or hyperparasitoids of *P. xylostella* (Fitton and Walker, 1992). The authors, however, believe that most of these may well be hyperparasitoids identified from rather dubious, single, casual rearings and, therefore,

require confirmation from further studies. Of the six species recorded in the present study, and which are also included in the above previous records, only *Elasmus* sp was obtained from a single rearing. The present study has, therefore, confirmed five species as credible records at least in Ghana. The other five species were both parasitoids and hyperparasitoids. Of these, *O. sokolowskii*, the commonest hyperparasitoid obtained in this study, had been reported as indigenous to various Islands in the West Indies, occurring wherever cabbage was grown (Alam, 1992).

Euplectrus laphygmae was the second most important parasitoid of *T. ni* having accounted for 35.5% of its parasitism. Parasitoids of the pest are however, not considered key mortality factors (Oatman and Platner (1969) cited in Capinera, 2008). The six species of parasitoids recorded from *S. littoralis* caused only 8% parasitism during the study period. When *C. plutellae* occurred together with *Euplectrus laphygmae*, a gregarious parasitoid which was found in this study to be restricted to *Trichoplusia ni* and *Spodoptera littoralis*, it caused a higher rate of parasitism in *T. ni* than did *E. laphygmae*. Only a single *Hellula undalis* was parasitized by *C. plutellae* during the study. However, in Malaysia, Sivapragasam and Chua (1997) reared a braconid, *Bassus* sp. and an ichneumonid *Trathala flavoorbitalis* (Cameron) from the larvae on cabbage. The authors nevertheless, noted that these parasitoids were not important mortality factors of the pest as they were present only at the end of the season and also in very low numbers.

Apart from the effects of parasitoids, the low incidence of *P. xylostella* in the major rainy season could also be attributed to the rains washing off the relatively small larvae. There were many instances in the present study when several larvae of

Plutella xylostella were observed drowned in water on the lower leaves of the cabbage plant after rains. In addition, during heavy rains on three occasions in the major rainy season (June), not a single *P. xylostella* larva was recorded on plants which were sampled after the rains. This seasonality can be exploited in the timing of planting to avoid heavy infestation and also to reduce irrigation costs. The drowning effect of rain on *P. xylostella* has been simulated in Asia where sprinkler irrigation systems in experiments considerably reduced pest numbers (Nakahara *et al.*, 1986; Tabashnik and Mau, 1996).

Wide variations in parasitism levels by *C. plutellae* had been recorded from locality to locality, season to season, and from country to country, even in areas with similar climates (Jayarathnam, 1977; Ooi and Chua, 1986; Hu *et al.*, 1997; Rowell *et al.*, 2005). It had also been observed that parasitism levels by this parasitoid could not exceed 60% (Ooi, 1979 a & b; Ooi, 1992). In the present study, mean parasitism rate recorded was significantly higher in the major rainy season ($68.6 \pm 12.9\%$) than in the minor rainy season ($9.9 \pm 7.1\%$). Seasonal variations of parasitism by this parasitoid were also noted by Yadav *et al.* (1974) but he on the contrary, observed that the rains reduced percentage parasitism. In China Liu *et al.* (2000) recorded 10 - 60% whilst in Thailand Rowell *et al.* (2005) recorded between 14 - 78%. In addition, the combined mean parasitism of $29.4 \pm 7.5\%$ caused by *C. plutellae* and *E. laphygmae* to *T. ni* in the major rainy season suggests the need to conserve these parasitoids. They are unquestionably valuable agents for biological control of *P. xylostella* and *T. ni* on cabbage in Ghana.

The relationship between diamondback moth and *C. plutellae*, was observed to be a clear and distinct density dependent one, with a positive correlation between them in all the three seasons in the present study. Cock (1985) also made similar observations and observed that rates of parasitism by *C. plutellae* was between 89 - 100% in the Caribbean, whilst Alam (1992) noted that parasitism rates could go up to 100% in Jamaica. The least correlation of 0.55 and the highest of 0.97 were observed in the minor rainy season and major rainy season respectively. The initial time lag between the parasitoid and its host in the present study during the minor rainy season and the major rainy season could be attributed to the very low infestation levels of the diamondback moth early in the crop season. Hu *et al.* (1997) and Mitchell *et al.* (1997b) considered this parasitoid inefficient because of its poor searching ability when pest populations were low. Ooi (1986) and Ooi (1992) also contended that in Malaysia, this parasitoid could not prevent diamondback moth numbers from rising in the dry season when pest populations were high. Among the reasons advanced for the inability of *C. plutellae* to increase with increasing pest numbers are the lack of understanding of its biology (Fitton and Walker, 1992) or the consequences of environmental factors such as temperature and humidity (Loke *et al.*, 1992). However, Ingham and Kfir (1997) indicated that in South Africa this parasitoid was effective when diamondback moth populations were high. Contrary to the observation by Ooi (1992), in the present study, *C. plutellae* caused a mean parasitism of $43.7 \pm 8.9\%$ of *P. xylostella* with a coefficient correlation of 0.66 during the dry season when pest populations were highest. Notwithstanding these contrasting observations, the presence of *C. plutellae* in all three seasons and its ability to increase with increasing pest numbers make it a good candidate for biological control of the

major Lepidopteran pest, *P. xylostella* as well as *T. ni* in the cabbage ecosystem in Ghana.

The ineffectiveness of *C. plutellae* in keeping diamondback moth populations down in some countries had also been attributed to activities of hyperparasitoids (Morallo-Rejesus and Sayaboc, 1992). The negative effect of hyperparasitoids had however, been refuted by other workers who argued that they are of little significance and of no economic impact (Robertson, 1939; Mustata, 1992). In the present study, the total composition of the four hyperparasitoid species was less than 8.0% and was mainly the facultative species *O. sokolowskii*.

The high parasitism rates caused by *C. plutellae* to diamondback moth on karate-treated plots at Weija, provide some support to the findings by Ooi (1992) that, this parasitoid has developed resistance or is tolerant to insecticides in the field. Furlong *et al.* (1994) noted that *C. plutellae* was more tolerant to pyrethroids than other parasitoids of *P. xylostella*. Loke *et al.* (1992) observed a mean parasitism of 48.6% whilst Liu *et al.* (2000) recorded substantial rates of parasitism even under very heavy insecticide pressure. In the present study, the mean parasitism of $81.3 \pm 4.1\%$ observed on the Karate treated plots in the major rainy season and $61.3 \pm 4.1\%$ in the dry season lend further credence to these observations. Nevertheless, further and more direct studies are required to determine the insecticide resistance status of this parasitoid on cabbage in Ghana in order to draw firmer conclusions.

The extremely low parasitism of the diamondback moth observed on the farmer's farm could be attributed to the indiscriminate use of the variety of insecticides applied

from very early in the season. Rowell *et al.* (1992) noted that, the main 'gap' in the occurrence and activity of diamondback moth parasitoids appears to be the critical period early in the season when farmers are most likely to treat with broad spectrum insecticides.

Even though substantial numbers of the parasitoids reared from *P. xylostella* hosts collected from Karate and neem seed water extract treated plots emerged, the parasitoids were adversely affected. Neem inhibited or arrested growth and development, and prevented the larvae that emerged from field parasitized hosts from pupating or spinning cocoon. Even when they spun their cocoon, on dissection, it was found that the larva had not undergone structural differentiation. Adult parasitoids that emerged from pests collected from Karate treated plots were short lived, living for only a day, or dying soon after eclosion or during eclosion. In some cases the thin line of weakness along the pupal case from where the adult would emerge was visible but they could not emerge and their heads were broken off. There was no significant difference between emergence rates of *C. plutellae* collected as pupae from Karate-treated plots ($81.3 \pm 8.19\%$) and unsprayed plots ($69.10 \pm 90\%$) in the major rainy season. This observation may be due to the rains diluting the effects of the insecticide.

The results of the laboratory studies on the direct effect of Karate on *C. plutellae* adults is similar to observations made by Condor (2007), who observed that the insecticide caused 100% mortality to adult *Diadegma mollipla*, another important parasitoid of *P. xylostella*. The implications of these are that Karate could reduce the

effectiveness of *C. plutellae* by directly eliminating them, or causing a decrease in the numbers that will be available to sustain succeeding generations of the parasitoids.

Even though the neem adversely affected development of the parasitoid in this study at the concentrations used, there is also evidence that, neem treatments do not affect parasitoids and can be compatible with Integrated Pest Management programmes when lower doses are used or depending upon the formulations (Charleston *et al.*, 2005; Haseeb *et al.*, 2006).

Previous studies had shown that certain pesticides were highly toxic to adult *C. plutellae* when sprayed directly at the recommended rates while others showed little to no toxicity (Kao and Tzeng, 1992; Perez *et al.*, 1995). The results also indicate that the choice of insecticide that could be integrated with *C. plutellae* for pest management on cabbage should be properly understood. Variation in the response of *C. plutellae* to the test insecticides, imply that an effective pest management strategy for *P. xylostella* that would include this parasitoid and chemical control can be developed. The results have also contributed in clarifying the relationships that are important in the integrated pest management of the diamondback moth and the other pests. Integrated pest management programme that is focused on conservation of local parasitoids will help alleviate the growing public concern regarding the effects of pesticides on vegetable growers and consumers. From the results obtained, an integrated pest management strategy based on either the use of lower doses of neem seed water extract or *Bacillus thuringiensis* and *Cotesia plutellae*, coupled with appropriate timing is recommended for the Weija vegetable irrigation company WEICO.

CHAPTER FOUR

4.0 BIOLOGY AND ECOLOGY OF THE PARASITOIDS OF LEPIDOPTERAN PESTS OF CABBAGE

4.1 Introduction

Parasitoids alone, or in combination with other control measures, have been employed against various cabbage pests with varying degrees of success (Mitchell *et al.*, 1997a, b; Mahar *et al.*, 2004). They are nevertheless a valuable control component and resource and, unless the important ones are made a part of any management strategy against the pests of cabbage, the plague of the major pest, *P. xylostella* and other related problems are likely to persist (Clausen, 1978; Lim, 1986; Liu, *et al.*, 2000; Pratisolli *et al.*, 2008). Parasitoids provide considerable impact and effective check on multiplication of the diamondback moth (Lim, 1992; Ooi, 1992; Hamilton *et al.*, 2004). In some countries, there is direct evidence that the action of parasitoids arrest or obliterate infestations of *P. xylostella* or keeps it under control (Ingham and Kfir, 1997). In some instances, reduction in pest population is so marked that the use of insecticides could become unnecessary (Waterhouse, 1992). Indeed, there are known cases of successful *P. xylostella* control in which the basic control component constituted parasitoids (Lim, 1986; Mustata *et al.*, 2006). However, investigations into the biology and ecology of the important parasitoids of *P. xylostella* are limited (Lim, 1986; Pratisolli *et al.*, 2008). Fitton and Walker (1992) suggested that the contradictory reports regarding the effectiveness of *C. plutellae* in reducing the population of the diamondback on cabbage could be due to a lack of understanding of the biology of this parasitoid in various countries. On the other hand, contribution of parasitoids in the control of the other pests on cabbage has not been encouraging or

clear (Talekar N. S. 1992; Sivapragasam and Chua, 1997; Capinera, 2008; Jayma and Ronald, 2007).

The guild of parasitoids recorded on the diamondback moth is large and varies from region to region, though not all of them are effective (Lim, 1986; Mustata *et al.*, 2006). Only a few species of *Trichogramma* and *Trichogrammatoidea* have been reared from the eggs. These, however, gave satisfactory results and good searching ability in the laboratory, but did not show promise in the field (Klemm *et al.*, 1993). Nevertheless, Keinmeesuke *et al.* (1992) observed that *Trichogrammatoidea bactrae* Nagaraja caused parasitism of 16.2 – 45.2% from diamondback moth eggs collected from the field.

The greatest control is provided by the larval parasitoid species belonging to the Hymenoptera genera, *Diadegma*, *Cotesia* and *Microplitis* (Sarfraz *et al.*, 2005). Attention is therefore increasingly being given to their use in controlling the major pest of cabbage worldwide. However, in Africa in general, and Ghana in particular, the identities and biology of members of the parasitoid complex are either not known or are very poorly known (Quicke, 1997; La Salle, CABI Bioscience UK Personal communication). Indeed, for any meaningful exploitation of the parasitoids associated with either the major pest or the other lepidopterous pests of cabbage in Ghana, it is vital that their biology and especially their behaviour in the field are very well understood. Understanding the biology of local populations of parasitoids would yield valuable information on host ranges in nature that can also be useful in rearing for augmentative releases in biological control.



The objective of this study was to determine the biology (life history, lifestyle, longevity and host preference) and ecology (searching and oviposition behaviour) of the parasitoids of the pests observed in this study, with emphasis on the dominant one based on laboratory and field data.

4.2 Materials and Methods

4.2.1 Field Sampling and Rearing of Host – *Plutella xylostella*

Cotesia plutellae was the predominant species observed from the Lepidopteran pests and was, therefore further studied in the laboratory in the Department of Zoology (now Department of Animal Biology and Conservation Science, DABCS) of the University of Ghana. In order to study the parasitoid, the host had to be obtained and reared. Larvae of *P. xylostella* were collected from cabbage at the experimental site at Weija. The larvae still attached to cabbage leaf were kept in petri dishes lined with wet filter paper and brought to the laboratory. Prevailing laboratory conditions were a mean temperature of 23 ± 2 °C and relative humidity of $45 \pm 1.0\%$. The larvae were individually placed on moist filter paper in petri dishes on the laboratory bench and were fed with fresh pieces of cabbage leaf daily and observed till the adult pest emerged. Emerging adults were put in mating and oviposition wooden cages measuring 45 x 45 x 45 cm and provided with 10% honey solution soaked in cotton wool and placed in a petri dish. A small cabbage seedling was placed in a beaker containing water and placed inside the cage for oviposition by *P. xylostella*. The eggs that were laid by *P. xylostella* were harvested still attached to the leaf and incubated in a petri dish lined with wet filter paper till hatching. Upon hatching, the newly emerged larvae were placed separately in a petri dish and fed with cabbage leaves.

4.2.2 Field Collection and Rearing of Parasitoids

Cotesia plutellae pupae that emerged from *P. xylostella* larvae that had been collected in the experimental plots were kept in tubes till emergence of adult parasitoids. In addition, parasitoid pupae still attached to pieces of cabbage leaves were carefully detached with a pair of forceps and brought to the laboratory. The adult parasitoids that emerged were fed on 10% honey solution and allowed to mate in small plastic transparent cages (11.0 x 7.0 cm) fitted with gauze for 24 hours before being used for the study.

Data for the other parasitoids (*Euplectrus laphygmae*, *Chelonus curvimaculatus*, *Oomyzus sokolowskii*, *Tetrastichus atriclavus* s.l., *Aphanogmus reticulatus*, *Charops* sp, *Brachymeria* sp, *Hockeria* sp, *Notanisomorphella* sp, *Elasmus* sp, *Pediobius* sp, *Trichomalopsis* sp, *Blepharella vasta* and *Peribaea orbata*) were taken from the field samples as well as in the laboratory where possible. As a result, the numbers of each species used varied depending upon availability.

4.2.3 Life History and Lifestyle Studies of *Cotesia plutellae*

A male *C. plutellae* was exposed to a female for 24 hours to allow mating in a transparent glass jar (7.0 x 6.0 cm) that had been provided with a streak of 10% honey solution and covered with a piece of gauze. The female was then aspirated through a slit made in the cover of the rearing jar into another prepared transparent jar (7.0 x 6.0 cm) containing a three-day old *P. xylostella* larva reared in the laboratory as described above (4.2.1), a piece of cabbage leaf and a streak of 10% honey solution as food for the pest and parasitoid respectively. The interaction between the adult female parasitoid and the diamondback moth host was observed. After 24 hours, the adult

female parasitoid was allowed to escape into a rearing cage and the host larva transferred into a petri dish lined with a wet filter paper and provided with a piece of cabbage leaf. The larva was observed daily till the parasitoid larva emerged or the host pupated. Food for the host was changed every other day till pupation of host or emergence of parasitoid larva. It was not possible to determine the egg incubation period inside the host so the total egg incubation and larval duration was determined for each individual parasitoid. The duration of the pupal period of the parasitoids was recorded. The nature of the newly emerged parasitoid larva and its appearance were noted. The spinning of the pupal case by the parasitoid larva and the position from which the adult parasitoid emerged from the pupal case were also noted. The sex of the parasitoid was determined after adult emergence based on the presence or absence of an ovipositor. Four replicates each consisting of five adult *C. plutellae* were used in the studies. The data were then pooled and the mean developmental periods determined.

4.2.4 Longevity Studies of *Cotesia plutellae*

To determine the longevity of mated and unmated *C. plutellae* adults, two experiments were set up. In the first experiment, 10 day-old unmated adult male and female parasitoids were kept singly in tubes and plugged with absorbent cotton wool. Each parasitoid was fed on a streak of 10% honey solution which was replenished every third day. In the second set-up, a newly emerged male was exposed to a female for 24 hours to allow mating in a transparent glass jar (7.0 x 6.0 cm). They were then separated and placed singly in glass tubes plugged with absorbent cotton wool and provided with a streak of 10% honey solution as food. Each parasitoid was observed daily till it died. The period between the beginning of the experiment and death was

recorded as longevity in days for each individual parasitoid. The data were pooled for each category and the mean longevity determined.

4.2.5 Oviposition Preference of *Plutella xylostella* Larvae by *Cotesia plutellae*

In order to determine the preferred diamondback moth host stages by *C. plutellae*, a no-choice experiment was conducted. Twelve newly mated parasitoid females were individually exposed to each of 3 day old (2nd instar), 6 day-old (3rd instar) and 8 day old (4th instar) larvae of the diamondback as described above. After 24 hours, the parasitoid was allowed to escape and the host larva transferred into a petri-dish lined with a wet filter paper and provided with a piece of cabbage leaf. The larva was observed daily and the piece of cabbage changed every other day till the host pupated or the parasitoid larva emerged. The number of diamondback moth larvae from which parasitoid larvae emerged for each larval instar was pooled and the percentage preference calculated.

4.2.6 Field Observations on Biology and Ecology of the Parasitoids

Field observations were carried out on the seven central plants of the unsprayed plots at the experimental site at Weija as the pests were sampled. The part of the plant where parasitism of pests occurred in the field was recorded. Searching and oviposition behavior of adults in the field were recorded. The number of parasitoids that emerged from a host, the developmental stage and the behavior of the parasitoid were also recorded. Parasitoid lifestyle was recorded as solitary when only one adult emerged from its host and gregarious when more than one adult emerged from its host. In addition, where possible the duration of larval and pupal stages of the other parasitoids were recorded from field samples of pests described in Sections 3.2.7 and

3.2.8 of this thesis. The sex ratios were calculated for each parasitoid species from the numbers of male and female adult parasitoids reared from field samples of pests but the numbers used varied according to availability. For *C. plutellae*, the sex ratio was calculated from 151 individuals reared from field-collected larvae of the diamondback moth.

4.3 Results

4.3.1 Biology and Ecology of *Cotesia plutellae*

4.3.1.1 Life History and Lifestyle of *C. plutellae*

The duration of the total life cycle of *Cotesia plutellae* in the laboratory at an average temperature of $23\text{ }^{\circ}\text{C} \pm 2$ and relative humidity of $45\% \pm 1$ was similar for males and females. It averaged 16.0 ± 0.5 days and 16.1 ± 0.3 days for males and females, respectively. The egg incubation plus larval developmental period averaged 9.1 ± 0.4 days for males and 9.1 ± 0.2 days for females. Pupal period was 6.9 ± 0.3 days and 7.1 ± 0.3 days for males and females, respectively.

The adult parasitoids mated on the same day that they emerged. During courtship, the males intensively fanned their wings around the females as they attempted to mount them.

Cotesia plutellae behaves as a solitary endoparasitoid and lays one egg per host. Thus, only one adult emerges from a parasitized host. The adult *C. plutellae*, after laying her egg in the larval host exhibited koinobiosis, allowing the host larva to feed and develop for some time. The final larval instar of the parasitoid emerged after about 9 days and immediately began spinning a creamish to off white cocoon whilst remaining very close to the host, most probably soliciting the needed physical support

from its host (Plate 4.1). The newly emerged final larval instar of *C. plutellae* was translucent, yellowish green and slightly curved. It usually emerged from the posterior part of the host near the proleg and stayed close to the host. The sclerotised mandibles of the parasitoid larva were distinctly visible as it spun the cocoon. Within 24 hours, it pupated on the leaf surface near the host (Plate 4.2). The pupa was firmly attached to the leaf surface. The newly formed cocoon was slightly rough and appeared as a thin net-like cover around the pupa. By this time the host had stopped feeding and looked pale. It became deformed as a result of the parasitoid exit hole and assumed a characteristic more or less 'C' shape (Plate 4.2) but was still capable of some movements. The unparasitised diamondback moth larva maintains its spindle shape (Plate 4.3).



Plate 4.1: Newly emerged *C. plutellae* larva (arrowed) and host

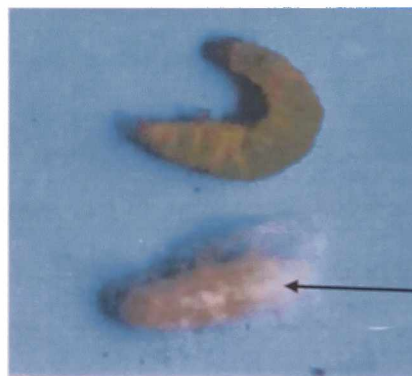


Plate 4.2: *C. plutellae* pupa (arrowed) and host



Plate 4.3: Unparasitised *P. xylostella* larva [x10]

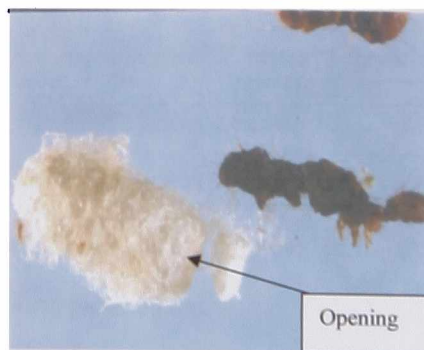


Plate 4.4: Empty pupal cocoon of *C. plutellae* (arrowed)

At the end of the pupal period, the cocoon opened at one end through which the adult parasitoid emerged (Fig. 4.4). Sometimes the cap remained attached or it was completely detached from the rest of the pupal case. By the time the adult parasitoid eclosed, the host carcass had dried up (Plates 4.4 and 4.5).



Plate 4.5: Carcass of *P. xylostella* after parasitism

3.1.2 Longevity of Mated and Unmated Adult *Cotesia plutellae*

Mated and unmated females lived for an average of 13.7 ± 1.1 days and 7.7 ± 0.6 days, respectively. On the other hand, mated and unmated males lived for an average of 15.8 ± 1.5 days and 7.0 ± 0.6 days respectively.

3.1.3 Oviposition Preference of *Plutella xylostella* Larvae by *Cotesia plutellae*

In the no-choice experiments, adult *Cotesia plutellae* attacked 2nd instar (3 day-old), 3rd instar (6 day-old) and 4th instar (8 day-old) larvae of *Plutella xylostella*, but with a preference for second and third instar larvae. Eighty percent (10/12) and 50% (6/12) of second and third instar larvae of the diamondback moth were parasitized, respectively as opposed to 33% (4/12) of the fourth instar larvae.

When presented with the large hosts (i.e 3rd - 4th instars), the parasitoid had more difficulty inserting her ovipositor to lay eggs. The host always put up a defensive behaviour, vigorously wriggling around the parasitoid and either dropping via a silken thread, or dislodging the parasitoid. Sometimes, the host flipped off the parasitoid so vigorously that it hit one side of the glass tube. After such an encounter the parasitoid always spent some time cleaning itself after which it made another attempt.,

1.3.1.4 Field Observations on Parasitism by *C. plutellae*

Cotesia plutellae normally parasitises the second or third instar larvae of the various Lepidopteran pests of cabbage, namely; *Plutella xylostella*, *Trichoplusia ni*, *Spodoptera littoralis* and *Hellula undalis* in the field. *C. plutellae* is, therefore, not strictly host specific though the results obtained from the field indicated that it preferred *P. xylostella*. In the field, the emerging parasitoid larva always laid very close to its host as was observed in the laboratory and pupation usually occurred on the ventral surface of the leaf. As the pupa aged, the thin cocoon which covered it was sometimes lost or washed off after rains. The pupae of *C. plutellae* emerging from *P. xylostella* were smaller than those from *T. ni* and they had an average length of 3.05 ± 0.01 mm (N = 20) compared to an average of 3.64 ± 0.06 (N = 20) mm for *T. ni*.

Cotesia plutellae was sometimes observed to attack older larvae of *T. ni* in the field, but the host was not killed and continued to develop till the parasitoid emerged after which the adult moth also emerged. In such cases, the emergence hole could still be seen on the host larva obviously not having been adversely affected. For example, five adults of *C. plutellae* emerged from three 3rd and two 5th instar larvae of *T. ni*

which later pupated and normal adult moths also emerged. Large larvae of *T. ni* were observed to be exceptionally defensive when the parasitoid attempted to oviposit in them. In the cases when *C. plutellae* parasitised larvae of *S. littoralis* and *H. undalis*, the adult parasitoid failed to emerge from its pupa. On the two occasions that multiple parasitism of *Cotesia plutellae*, *Euplectrus laphygmae* and another unidentified gregarious parasitoid was observed, *C. plutellae* out-competed them, with the adults emerging whilst the other species died. When both *C. plutellae* and *E. laphygmae* parasitised *T. ni* larva, the former species emerged, with only a few of the latter emerging.

As the crop matured and was ready for harvest, it was common to see a number of parasitised hosts, parasitoid pupae and newly emerged parasitoid larvae close by the hosts together on one leaf. Adult parasitoids were often observed in the field systematically and vigorously tapping their antennae and ovipositor along the cabbage leaf surfaces from the edges, obviously searching for hosts. This was particularly common when *Plutella xylostella* populations were low. When the crop had matured, several of the parasitoids were observed hovering above the plant.

The sex ratio was slightly higher for males than for females. Field collected samples gave a sex ratio ratio of 1: 1.06 (73 females: 78 males).

4.3.2 Biology and Ecology of Other Parasitoids

Charops sp (Ichneumonidae)

This was found to be a solitary parasitoid of late larval instar of *Trichoplusia ni* and *Spodoptera littoralis*. It was in turn parasitised by a *Brachymeria* sp and was present during the dry and minor rainy seasons from October to March. The larva (N = 2) that emerged from field parasitized host was amorphous in shape, pale brown (off white) and was very soft and flexible. It pupated within an hour or two after emergence from the host. It formed a brown oval shaped pupal case which had a ring of conspicuous black spots close to either ends of the pupal case (Plate 4.6). The pupal case measured between 6.0 - 6.9 mm long in females and 5.2 - 5.5 mm in males. The ends were slightly flattened and in the field, it hanged on the ventral side of the leaf by means of a strong silken thread (Plate. 4.6). The pupal period ranged from 6 - 9 days in females with an average of 6.5 days. The male pupal period lasted seven days for each of a sample of five pupae. The adult parasitoid emerged through the sub-dorsal side of the case above the ring of black spots (Plate 4.6).

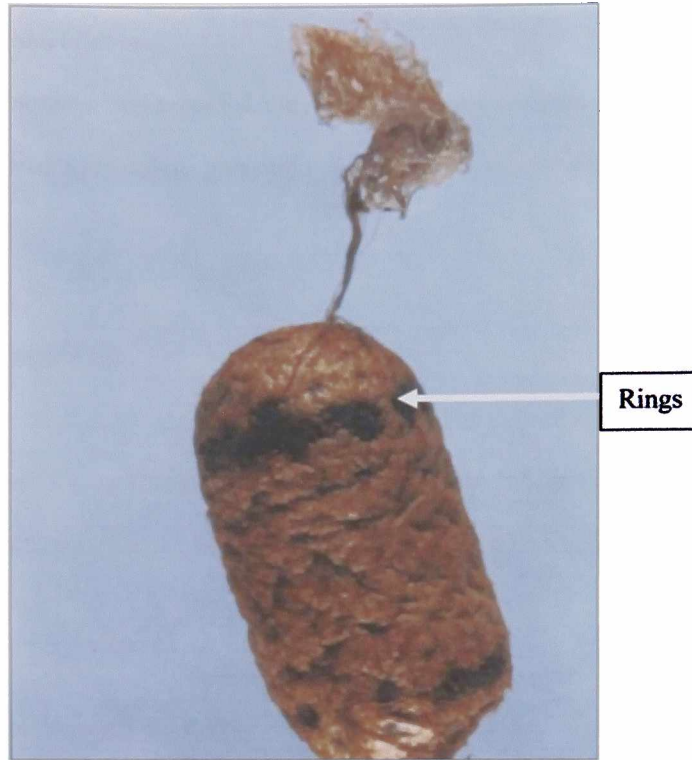


Plate 4.6: Pupa of *Charops* sp. [x 12] hanging by thread after emergence of adult parasitoid

***Chelonus curvimaculatus* (Ichneumonidae)**

This species was observed to be a solitary parasitoid of larvae of *Spodoptera littoralis*.

Only two males were recorded in the minor rainy season.

***Brachymeria* sp (Chalcididae)**

A species of *Brachymeria* was recorded as both a primary solitary parasitoid of pupa (N = 5) of *T. ni* and a secondary parasitoid of *T. ni* via *Charops* sp. Specimens that were reared as hyperparasitoids from *T. ni* via *Charops* sp were smaller measuring between 3.0 - 3.2 mm long compared to those that acted as primary parasitoids which measured between 5.4 - 5.6 mm long.

***Hockeria* sp (Chalcididae)**

A species of *Hockeria* was recorded only on two occasions from the diamondback moth larvae. It was a gregarious parasitoid with a male to female sex ratio of 1:1.5 (N = 10).

***Elasmus* sp. (Elasmidae)**

This was observed as a gregarious hyperparasitoid of diamondback moth larva via *Cotesia plutellae*. The adults emerged from the lateral side of the parasitoid pupa. It was recorded only once (N = 4) during the dry season in March when the cabbage was ready for harvesting.

***Euplectrus laphygmae* (Eulophidae)**

These were active gregarious koinobiont ectoparasitoids of third to fourth larval instars of *T. ni* and *S. littoralis*. When *E. laphygmae* attempted to oviposit in the host caterpillar it flipped off the parasitoid with its abdomen. The adult parasitoid always persisted until the ovipositor was successfully inserted after which the caterpillar did not attempt to flip it off but continued to struggle till the parasitoid left. The female laid more than one egg in a host. The newly hatched parasitoid larvae were small green, round to oval bodies with thin pale transverse bands on the body. They partially buried themselves in the host and fed on the tissues from the outside (Plate 4.7). The mature larvae formed aggregations on the dorsal surface of the host, usually around the middle patch from where they all fed (Plate 4.8). The larvae when matured were barrel or spindle shaped and fully emerged from the caterpillar host. Unlike the unparasitised *T. ni* caterpillar which was bright green, the host at this time became very pale, sluggish and stopped feeding (Plate 4.8). The parasitoid larvae

later turned slightly pale and migrated to align themselves along the entire ventral surface of the host and pupated within twenty-four hours (Plate 4.9).



Plate 4.7: Newly hatched larvae of *E. laphygmae* [x 2.7] (arrowed) penetrating host to feed



Plate 4.8: Larvae of *E. laphygmae* (arrowed) about to migrate to pupate

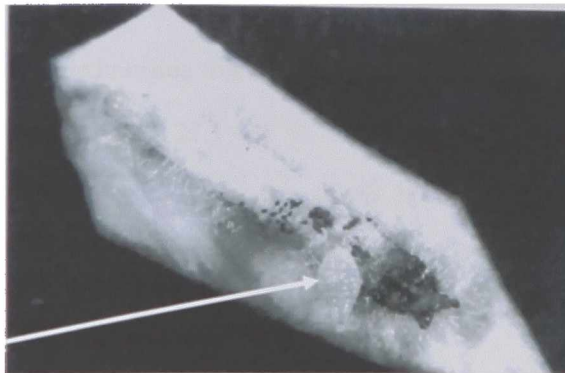


Plate 4.9: Mature larva of *E. laphygmae* migrating (arrowed) down the host to pupate

Each larva spun a loose cocoon within which it pupated such that each remained separated from the other. A secretion fixed the cocoons to the host and also to the substrate (cabbage leaf) which rendered it difficult to dislodge. By this time, the host was a dead dark brown flattened carcass with remnants of the cocoons (Plate 4.10).

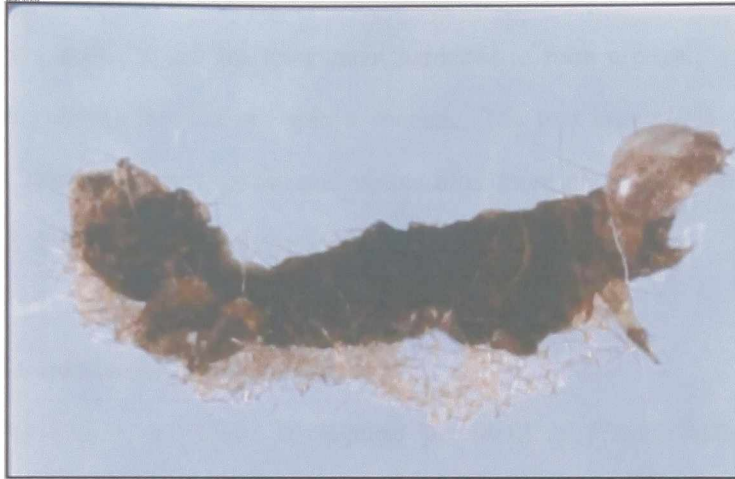


Plate 4.10: Carcass of *T. ni* larva after parasitism by *E. laphygmae*

The pupal period varied ranging from 4 to 13 days depending upon temperature in the laboratory which ranged from 22.5 - 28 °C. The progeny size per host varied from 2 - 17 individuals depending upon the size of the host and was sex biased towards females. The mean ratio of males to females recorded from field parasitism of *T. ni*: was 1.0:6.5 (N = 45). Size variation was observed in adults of *E. laphygmae* depending on the number emerging from a particular host. Larger hosts ranging in length from 16 - 20 mm had more progeny (7 - 13) than smaller ones less than 10 mm. Where 2 - 3 individuals emerged from large hosts, they were bigger in size. Where progeny size was large (15 - 17) a mixture of small and big females were observed. Where progeny size was not more than four (N = 5), only females were produced. In four instances a male each emerged from fourth instar larva of *T. ni*.

***Notanisomorphella* sp. (Eulophidae)**

A solitary parasitoid species of *Notanisomorphella* (N = 2) was reared from third instar caterpillar of *Spodoptera littoralis* and were both males. It was recorded at Weija during the dry season when the cabbage was cupping. The larva that emerged from the host in the laboratory was soft, pinkish, and apodous. Prepupal period was three days during which the integument hardened to form a pupa. The pupa was creamish, exarate and did not spin a cocoon. The two brown eyes were clearly visible. Antennae and legs became visible after three days, after which the adult emerged the following day giving a pupal period of four days.

***Oomyzus sokolowski* (Eulophidae)**

This was both a gregarious larval-pupal parasitoid of *Plutella xylostella* and a hyperparasitoid of the same host larva via *Cotesia plutellae* in the rainy season (April and May). The parasitoid emerged from the diamondback moth larvae that had been parasitized by *C. plutellae* as well as pupae of the diamondback moth that was collected as larvae from the field. At three different temperatures and relative humidity conditions of 25 °C and 70%, 22 °C and 45%, 20 °C and 37% in the laboratory, the pupal periods of field parasitized larvae were 11 (N = 6), 19 (N = 11) and 21 (N = 5) days respectively. The adults emerged through a small opening in the middle of the dorsal surface of the host. The size of the progeny when it behaved as a parasitoid was greater than when as a hyperparasitoid. Ratio of male to female from diamondback moth pupae (N = 24) was 1:11 and from *C. plutellae* (N = 17) was 1:4.7.

***Tetrastichus atriclavus* Waterston s.l. (Eulophidae)**

This was a gregarious primary parasitoid of both *Trichoplusia ni* larva and a secondary parasitoid via *Cotesia plutellae*. The adults (N = 13) emerged through a small opening in the center of the dorsal surface of the host.

***Pediobius* sp. (Eulophidae)**

A gregarious species of *Pediobius* was recorded as a parasitoid of the diamondback moth larvae and pupae (N = 4) in the major rainy season (May - June).

***Trichomalopsis* sp. (Pteromalidae)**

This was a primary solitary parasitoid and a hyperparasitoid of the diamondback moth via *C. plutellae*. The adult was not active and emerged by a small opening on the sub-dorsal side towards the apex of the cocoon (N = 35). This species was observed in the major rainy season from July to August.

***Aphanogmus reticulatus* (Fouts) (Ceraphronidae)**

This is a gregarious endoparasitoid and hyperparasitoid of the pupa of *Plutella ylostella* via *C. plutellae* (N = 33) in the major rainy season. It was not active and flew for short distances giving the impression of hopping. Emergence hole of the adult was around the middle portion of the pupal cocoon. The number of individuals emerging per host was 3 - 11 and was female biased. Ratio of males to females was 1:9.8.

***Blepharella* sp. near *vasta* (Karsch) (Tachinidae)**

This species is a Koinobiont larval-pupal endoparasitoid which attacked late larval instars of *Spodoptera littoralis*. For a period of three days before pupation, the host larva became quiescent and shortened and its cuticle became brown and crinkled after which it pupated. The parasitoid continued to develop within the pupa of *S. littoralis* from which it emerged as a solitary species (N = 2) (Plate 4.11).



Plate 4.11: Adult *B. sp. nr. vasta* [x 2.5] and pupal case of *S. littoralis* from which it had emerged

***Peribaea orbata* (Wiedemann) (Tachinidae)**

This species was collected during the minor rainy season from October to December when the cabbage had headed. It is a gregarious parasitoid of the larvae of *S. littoralis*. The parasitoid larvae (N = 29) fed within the host larva and reduced it to a slightly liquid mass of tissue and later emerged as pale maggots by which time the host was dead. They then continued to feed externally on the mass of liquefying tissue for 3 - 4 days after which they pupated in small dark reddish puparia (Plate 4.12). The pupal period lasted for 6 to 11 days at 26 °C in the laboratory. Five to eleven adults emerged from a single host. The adult parasitoid emerged from the puparium through a neatly cut opening or a rugged opening.



Plate 4.12: Adult *P. orbata* [x 14] and its pupal case

4.4 Discussion

The most abundant and important primary parasitoid of *P. xylostella* and *T. ni* recorded in this study is *Cotesia plutellae*. It is one of the three most important species recorded elsewhere in Asia, parts of Africa and Central Europe (Waladde *et al.*, 1997; Anene and Dike, 1996; Mitchell *et al.*, 1997 a & b; Ingham and Kfir 1997). The mean total developmental period of 16.1 days of the parasitoid suggests that it may take at least, this length of time before the first adults would emerge from the eggs laid by the first females to arrive on cabbage, by which time pest numbers would have increased.

It has usually been assumed that *Cotesia plutellae* is host specific to *P. xylostella* (Talekar and Griggs, 1986; Talekar, 1992; Fitton and Walker, 1992). However, Fitton and Walker (1992) have compiled from the literature twenty Lepidopteran host species, but questioned the identity of most of these records, and suggested the need for a critical appraisal of host specificity. The results obtained from this study

indicated that, at least in southern Ghana, *C. plutellae* is not host specific. It was observed to parasitize four other Lepidopteran pests on cabbage, i.e. *Trichoplusia ni*, *Spodoptera littoralis* and *Hellula undalis* but it, undoubtedly, showed a preference for *P. xylostella*.

Contrary to observations in parts of South East Asia (Talekar, 1992), in the present study, none of the first larval instars of *P. xylostella* collected from the field was parasitized by *C. plutellae*. This parasitoid may also be adapted to specific host size and therefore likely to shift to any other hosts which fall within that size range in the absence of adequate numbers of *P. xylostella*. It was observed that large host larvae of *T. ni* and *P. xylostella* were more defensive than smaller ones and always vigorously flipped them off when this parasitoid tried to oviposit. Baur and Yeargan (1994) and Brodeur *et al.* (1996) also recorded that defensive behaviour increased with host age of caterpillars. Kawaguchi and Tanaka (1999) and Shi *et al.* (2002) concluded that parasitism by *C. plutellae* decreased sharply with increasing host age in the fourth instar and approached zero in host larvae that had gone beyond 37% of the fourth stadium. This suggests that the acceptance phase might be used as a reliable indicator of its host specificity to *P. xylostella* and younger stages of *T. ni*.

The fact that *C. plutellae* was not restricted to *P. xylostella* is not expected to have negative implications on its use for biological control of *P. xylostella* as it has a preference for it. It was also able to out-compete other parasitoids including *E. laphygmae* when there was multiple parasitism. Fitton and Walker (1992) have suggested that records of species of the Braconid genus *Chelonus*, as parasitoids of the diamondback moth should be treated as doubtfully correct. The present study has

however, confirmed that in Ghana, *Chelonus curvimaculatus* Cameron does not parasitise *P. xylostella* instead, it parasitised *S. littoralis*. Quartey (1975) referred to a species of *Chelonus* parasitizing a stem borer species in Eastern Ghana, but it has not been possible to recover this specimen for examination and comparison with the specimen observed on cabbage in the present study. This is the first time a parasitoid species belonging to the genus, *Chelonus* has been recorded from *S. littoralis* on cabbage in Ghana.

Charops species have been reared from rice stem borers and *Acraea terpsicore* L. in various parts of Ghana such as Goaso, Kumasi, Atwoabo and Tokwabo (Forsyth, (1966; Duodu and Lawson, 1983), but the observation of a new *Charops* sp as a parasitoid of *T. ni* and *S. littoralis* in Ghana is a first record.

Species of *Brachymeria* had been recorded as parasitoids mainly from pupae of Lepidoptera, a few Coleoptera, Hymenoptera and Diptera. Boucek (1988) noted that some species are obligatory or occasional hyperparasitoids but others are known to be solely primary parasitoids. Members of this genus can act as both parasitoids and hyperparasitoids as shown in this study and earlier observed by Boucek (1988) and Ganeshan *et al.* (1997).

Several species of *Hockeria* are known to parasitise pupae of small to medium sized Lepidoptera, some of which are Tortricidae, Pyralidae and Yponomeutidae (Boucek 1988), (La Salle, pers. comm.). The present record from the diamondback moth pupae on cabbage has added to the list of recognized hosts.

Elasmus species had been recorded as hyperparasitoids of the diamondback moth by Fitton and Walker (1992). This is the first record of this hyperparasitoid of the diamondback moth via *C. plutellae* on cabbage and in Ghana.

Euplectrus laphygmae is widely distributed in Africa, and had been recorded mainly from species of *Plusia* Latreille and *S. littoralis*, all in the family Noctuidae (Ferriere, 1941; 1947; Boucek, 1988; Ganeshan *et al.*, 1997). However, this is the first record of *E. laphygmae* in Ghana and also as a parasitoid of *T. ni* on cabbage. Zhu and Huang (2003) did not list Ghana among the African countries with records of this species in their study of the Genus *Euplectrus*.

Notanisomorphella species had been recorded as parasitoids of small leaf mining insects (Lepidoptera and Hispine beetles). One species had been recorded from spider egg sacs, possibly as a hyperparasitoid (Boucek, 1988). Various species had been recorded in Southern Europe, throughout Africa and warmer parts of Asia and Australia. It is recorded here in Ghana for the first time as a solitary parasitoid of young larvae of *S. littoralis*.

The status of *O. sokolowskii* in the trophic system of cabbage appears to be controversial. It had been recorded as parasitoids, mainly of Coleoptera (Boucek, 1988) and as hyperparasitoids of the diamondback moth (Chelliah and Srinivasan, 1986; Mahmood *et al.*, 2004). Wakisaka *et al.* (1991) (cited in Talekar and Hu, 1996) had also observed that *O. sokolowskii* was a pupal parasitoid of the diamondback moth. Talekar and Hu (1996) showed that in the laboratory, *O. sokolowskii* failed to parasitise pupae of the diamondback moth and argued that it was a larval parasitoid.

In the present study, however, this parasitoid was reared from both field collected diamondback moth larvae that had been parasitized by *C. plutellae*, as well as from field collected diamondback moth larvae that later pupated in the laboratory. These suggest that it acted as a hyperparasitoid of the diamondback larvae via *C. plutellae* as well as a larval-pupal parasitoid of the diamondback moth. . 2006).

Tetrastichus atriclavus s. l. had been recorded in this study as a primary and a hyperparasitoid of *T. ni* via *C. plutellae*. They had also been observed from pupae of Lepidoptera and sometimes, as hyperparasitoids (Boucek, 1988) as observed in this study.

Elsewhere, species of *Pediobius* had been recorded as primary or secondary parasitoids of eggs, pupae and sometimes larvae of Lepidoptera, Coleoptera, Diptera, Hymenoptera and a few others, including spider egg masses (Burks, 1966). Forsyth (1966), in his book on the agricultural insects of Ghana, made no record of *Pediobius* species. The observation of a *Pediobius* sp as a parasitoid of the diamondback moth larvae and pupae on cabbage appears to be a first record in Ghana.

Graham (1969) indicated that, the typical hosts of *Trichomalopsis* species are pupae of Coleoptera and Lepidoptera. In the present study, they were reared as primary parasitoids and hyperparasitoids of the diamondback moth larvae via *C. plutellae*.

This is the first time *A. reticulatus* has been recorded as a hyperparasitoid of *Cotesia plutellae* via *P. xylostella* on cabbage in Ghana. The species is a widespread indigenous African species, hyperparasitic on lepidopteran hosts via *Apanteles* sp. and

Cotesia sesamia (Cameron) (Polaszek and La Salle, 1995). The authors reared *A. fijiensis* (Ferriere) from stem borers in Ghana. The species was also recorded as a hyperparasitoid of *C. plutellae* in Barbados by Cock (1985).

Peribaea orbata parasitized only *Spodoptera littoralis* in Ghana. It is known to be a common African species and parasitizes various species of Noctuidae including *Helicoverpa* and *Spodoptera* spp. (pers. com. N. Wyatt, British Museum Natural History).

Blepharella sp. near *vasta* is also restricted to *S. littoralis*. The species probably parasitizes lepidopterous larvae, as do other members of this genus (pers. com. N. Wyatt, British Museum Natural History).

For the first time in Ghana, this study has provided and illustrated the guild and complex of parasitoids and hyperparasitoids of the major Lepidopteran pests on cabbage in three seasons at the experimental site. Of the species of the three important genera of parasitoids recognized worldwide, *Cotesia plutellae* is the most important in southern Ghana. Very little information on parasitoids attacking *T. ni* exists possibly because of its relatively insignificant pest status on cabbage. The results of this study have laid a good foundation for further research in Ghana on the biology and ecology of parasitoids that would help in our understanding of the dynamics in the entire cabbage ecosystem and be exploited for integrated pest management strategy to control the pests.

CHAPTER FIVE

5.0 DESCRIPTION OF STAGES OF LEPIDOPTERAN PESTS, BEHAVIOUR AND DAMAGE

5.1 Introduction

Cabbage is an important vegetable crop worldwide and in Ghana it is the most important in the family Cruciferae. However, attack and damage by the complex of Lepidopteran pests make its production difficult (Bangnikon, 1996; Obeng-Ofori *et al.*, 2007). These pests are however, of unequal importance and their ecological characteristics and nature of damage may also differ depending on local climatic conditions, country and variety of cabbage (Ooi, 1986; FAO, 1992; Abdel-Razek *et al.*, 2006). There are also variations in biological and morphological parameters of the different stages of the pests on cabbage in different locations and countries (Salinas, 1986; Sarfraz *et al.*, 2008). It is, therefore, necessary that the specific niches that these pests occupy on the plant and the nature of damage caused in relation to the cabbage variety, and local conditions should be well understood in order to implement effective management strategies. This will also ensure that the parasitoids are protected through targeted and more efficient application and appropriate timing of insecticides in an Integrated Pest Management programme.

The objective of this study therefore, was to describe the stages of the pests observed in this study in relation to behaviour and damage on cabbage to enable their recognition, identification and management.

5.2 Materials and Methods

5.2.1 Rearing of Lepidopteran Pests

Eggs of *P. xylostella*, *T. ni* and *S. littoralis* attached to cabbage leaves were cut off with a pair of scissors from cabbage plants on an unsprayed plot at the experimental site in Weija, 39 days after transplanting and taken to the laboratory in the Department of Zoology, University of Ghana. Eggs of *H. undalis* and *H. armigera* were not included as they were not observed. One, three and 10 leaves of cabbage were sampled for *P. xylostella*, *T. ni* and *S. littoralis* respectively. Records of the distribution and sizes of egg batches on the leaves were taken on the same day. Each leaf was cut into six pieces and kept separately on a wet filter paper in a petri dish placed on a bench in the laboratory. They were maintained at 12:12 hours of light/dark regime till they hatched. Ten newly emerged larvae of each species were separated singly into petri dishes on the 3rd day and provided with pieces of young cabbage leaves (KK cross variety) placed on wet tissue paper. The food was changed every day till pupation. Daily observations were made on the development, behaviour and morphology of the developmental stages of each species till the adults emerged. In addition, the patterns of damage by the larvae maintained singly in petri dishes (14 cm wide) with a whole cabbage leaf and also on cabbage plants in cages in the laboratory were observed and photographed.

Forty newly emerged adult males and females of *P. xylostella* were kept in each of two wooden oviposition cages (45 x 45 x 45 cm) with young cabbage plants in water and maintained on 10% honey solution soaked in a petri dish. Courtship, mating, and oviposition behaviour were observed at 8 hours, 12 hours, 17 hours and 21 hours for 5 days. The cages were observed daily and the leaves with eggs were either removed or

the whole plant was removed and replaced. Morphological studies were made of the larvae, pupae and the adults. All the experiments were carried out at a mean temperature of 27 ± 0.2 °C and relative humidity of $55 \pm 1.0\%$.

Visual observations were also made in the field of all the pests (*P. xylostella*, *T. ni*, *S. littoralis*, *H. undalis* and *H. armigera*) on the seven central plants of the unsprayed plots at the experimental site as they were sampled. Observations regarding when they appeared on the cabbage plant, their location, posture, feeding pattern and movements were recorded and photographs taken.

5.3 Results

5.3.1 Description of Stages of Lepidopteran Pests, Behaviour and Damage

5.3.1.1 *Plutella xylostella* (Linnaeus)

Eggs of *P. xylostella* were observed on cabbage plants 18 - 19 days after transplanting. The female laid her eggs singly or in small batches of two to six, usually on the ventral surface of the leaf. For a total of 150 batches of eggs collected from the three leaves, 69.3 % were laid on the ventral surface and 30.7% on the dorsal surface. Of the 150 egg batches, 48.7% were laid singly, 31.3% in groups of two and the rest in groups of three to six (Table 5.1 and Plate 5.1).

Table 5.1 Percentage of Eggs Laid in a Batch by *P. xylostella* in the Field

Number of Eggs in a Batch	% of Total
1	48.7
2	31.3
3	8.7
4	5.3
5	2.0
6	4.0

Number of Batches = 150

In the laboratory, the eggs were usually concentrated at the lowest part of leaves of plants standing in water. On two occasions egg batches of 12, 17, and 18 were observed very close to the base of the leaf. Sometimes the eggs were deposited very close to the leaf stalk. Eggs were also laid on the sides of the cage. The eggs were always cemented to the substrate in a way that made it impossible to remove them without causing damage to either the eggs or the leaf.

In the field, eggs were often laid close to leaf veins and in depressions on the leaf. The eggs were creamy and sausage or oval shaped (Plate 5.1).

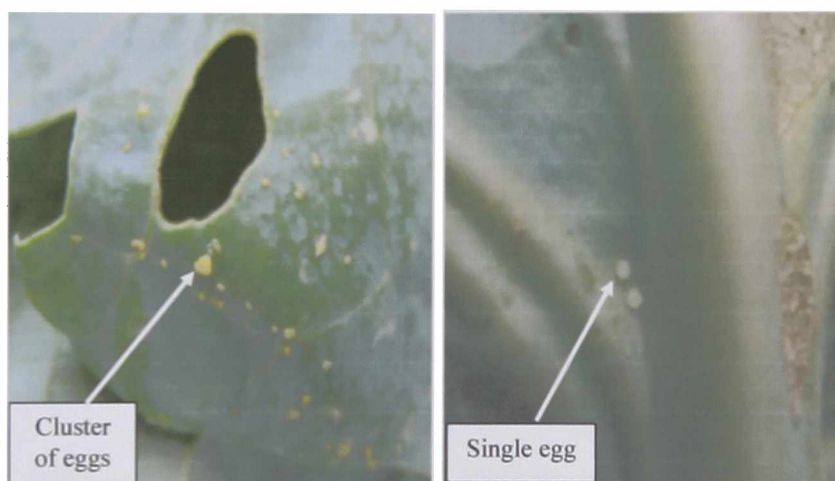


Plate 5.1: Eggs of *P. xylostella* [x 6] on cabbage leaf

The newly emerged caterpillars were pale green, slightly hairy and had black heads. As they grew the colour deepened and they lose their hairs. The larvae of *P. xylostella* were more or less spindle-shaped (Plate 5.2). The first instar caterpillars buried their heads in the underside of the leaf and fed from there, leaving small punctures which made the surface of the leaf looked densely punctured. Even though the second to fourth instars also fed from the ventral surface, they chewed from the

surface leaving the upper epidermis looking like a pale or white patched area which later dried up to form the characteristic 'windowing' associated with damage by this pest (Plate 5.2). The characteristic black faeces were always associated with damage on cabbage.



Plates 5.2: Mature larvae of *P. xylostella* [x 3] and damage on cabbage leaf, faeces are arrowed

The caterpillars of *P. xylostella* started attacking cabbage from two-week old seedlings to maturity. They were usually found on all parts of the plant but often concentrated on young leaves in the inner portions of the plant and on the upper leaves. The young caterpillars sometimes hid in the growing point of the plant and may go unnoticed. Sometimes, mature caterpillars bored into the developing head or small mature heads and some effort was usually needed to pull them out. They often fed close to each other on the leaf and also aggregated on a few plants whilst others had zero to few individuals on them. The caterpillars were very active and wriggled violently backwards or dropped off the plant via a silken thread when disturbed. They hung unto the thread and later climbed back unto the plant. The mature caterpillar

could grow up to 12 mm at a mean temperature of 27 ± 0.2 °C and relative humidity of $55 \pm 1.0\%$.

Mature caterpillars moved to the lower parts, usually on the ventral surface of the leaf, to pupate. They also pupated on the heads when cabbage was maturing. Pupation took place after a pre-pupal period of one day. The pre-pupa was either deep green or bright green and was enclosed in a woven white silken net-like pupal case (Plate 5.3a). The pupa turned pale brown after one day (Plate 5.3b) and varied in length from 6 to 7.5 mm.



**Plate 5.3a: Pre-pupa of
P. xylostella [x 6]**



**Plate 5.3b: Mature Pupa of
P. xylostella [x 4]**

Adults of the diamondback moth were small slender moths. The male was dark brown to dark grey whilst the female was lighter brown. At rest, the wings meet above the body and display three more or less diamond-shaped pale to creamy patterns (Plate 5.4) that extend from the base of the fore-wing along the posterior to the pre-apical part. The inner margins of these patterns are slightly darker than the rest of the body. At this posture, the rear ends of the wings appear slightly upturned from lateral view. The posterior part of the hind wing of the male had a fringe of hairs

longer than in the female. As a result, the posterior end of the male appeared wider than that of the female.

The typical pale diamond-shaped marks on the wings are less conspicuous in the female because of its lighter colour. However, when one is confronted with only one sex it may be impossible to sex them using the colour variation.



A



B

Plate 5.4: Adult *P. xylostella*
(A-Female [x 3.8], B-Male [x 3.5])

The female was smaller than the male and its length ranged from 5 - 6 mm (average = 5.4 mm). Length of the male ranged from 6.5 - 7.5 mm (average = 6.7 mm). Wing span was between 12.5 - 14.0 mm and 12 - 13 mm for males and females respectively.

In the laboratory, mating took place at dusk around 17.30 hours onwards soon after adult emergence. Courtship behaviour was exhibited by the male prior to mating. It vigorously flapped the wings whilst encircling the female and then attempted to pair up with her. Unwilling females were aggressively courted and forcibly copulated with. Sometimes, a pair in copula was disturbed by other courting males that attempted to dislodge the male in copula. Copulation lasted from 1-1^{1/2} hours, during which period the pair remained motionless. During mating, the posterior part of the

hind wings of the male remained opened and covered the posterior part of the female. Pre-oviposition period lasted one day in the populations that were studied.

In the field, the moths hovered about on the lower parts of the cabbage leaf on the shady ventral side. On very hot days, especially at noon when temperatures were very high between 30 - 31 °C, they sought refuge under the ventral surface of the leaf or on the lower parts of the inner surface of the leaves. In such situations, the adults could be easily captured. Adults arrive on the cabbage plant at dusk, just before sunset.

5.3.1.2 *Trichoplusia ni* (Hübner)

All stages of *T. ni* were found on the underside of the leaf. The eggs were whitish to pale greenish and roundish. They were laid singly on the plant. Out of 100 batches of eggs examined on a leaf, 98% were laid singly and one each in batches of two and three.

When the eggs were ready to hatch they turned greyish to black. The first larval stage of *T. ni* was pale greenish with black heads and always assumed the typical looping posture which made their identification in the field relatively easy. They have three pairs of legs on the abdomen towards the posterior region. The young caterpillars may have green or black thoracic legs. After the first moult the caterpillars may be yellowish green or dark green. The black heads and legs also turned green. They turned bright green or became greener as they grew and had two white lateral stripes, one on either side of the body (Plate 5.5). Before moulting, the pale lateral stripes disappeared and the caterpillar turned very bright green.

The caterpillar was usually found on the lower leaves of the plant where they were almost always in the characteristic looping posture. Occasionally, they might stretch out and hold fast tightly with both ends of the body along the leaf especially towards the leaf margin. They chewed large pieces of the leaf in between the midribs making the leaf skeletonised, or with large open rectangular areas on the leaf. The feeding activities of the first and second instars resulted in small roundish holes or punctures on the ventral surface. They also moved onto the heart or inner leaves, deep between the bases of the cabbage leaves and heads to feed. In this position, the mature caterpillars could not be easily noticed on the plant. Their presence may also be detected by large accumulations of sticky pale green almost transparent faeces which looked like beads at the feeding sites.

Mature *T. ni* caterpillar usually move down the ventral surface of the leaf to pupate. Pupation took place in a loose white silken gauze-like material (Plate 5.6.) usually towards the base of the leaf. On older cabbage plants, pupation took place at the inner sides of the base of the leaf or on senescing leaves close to the stem of the plant. The newly formed pupa is bright green and could be seen lying in its transparent white cocoon (Plate 5.6). The pupa turned brown as it aged. It was not tightly glued to the leaf and could be easily removed. The pupae ranged in length from 12 to 18 mm.



**Plate 5.5: Mature larva of
T. ni [x 4.8]**



**Plate 5.6: Freshly pupated *T. ni*
[x 3.7]**

The adult is a brown to dark brown medium sized moth ranging in length from 15 - 17 mm. There is a shiny creamish spot and a tear-drop or 'u' shaped spot centrally on the forewing (Plate 5.7). The two spots may be joined in some specimens. Wing span ranged from 27 - 33 mm.



Plate 5.7: Adult of *T. ni* [x 4.0]

5.3.1.3 *Spodoptera littoralis* (Boisduval)

The eggs of *S. littoralis* were laid in large batches of between 50 and 200 usually on the underside towards the tip or middle of the leaf. In a few cases there were less than 40 eggs per batch. Out of ten batches of eggs collected in the field, two batches contained 30 and 40 eggs. The remaining eight (80%) had between 50 and 200 eggs per batch.

The eggs were creamy white or off-white and the whole mass was covered with a brownish or buff fluffy material (Plate 5.8). The egg mass could be up to three layers, with the lowest layer being the largest.



Plate 5.8: Egg mass of *S. littoralis*[x 12]

Source: Berg and Cock, 2000

At hatching, the caterpillars formed aggregations where they fed and grew rapidly and dispersed soon after. In the laboratory, the dispersal commenced after two to three days. The caterpillars, at this stage were pale green and had black spots with hairs extending out of them. The colour of caterpillars from the same batch of eggs became variable as they moulted from one instar to the other but the head remained pale brown. The colour of the caterpillars was yellowish pink, pale green, greenish brown or pale yellow (Plates 5.9a - d). There was a wider variation in colour in the younger instars than in older ones.



Plate 5.9a-d: Variable colouration in young larvae of *S. littoralis*

At maturity the caterpillar measured between 24 - 27 mm long and the general body colour was variable from brown to dark brown. The mature caterpillars were capable of stretching themselves to about one and half times the length to 36 - 50 mm. The two black spots behind the head and at the posterior end became more conspicuous (Plate 5.10) as they matured. Sometimes the anterior pair was not very conspicuous and might be brownish. In addition, there were two pairs of smaller eye-like black spots in front of the spots behind the head. These smaller ones had white or pale portions near the middle.



Plate 5.10: Mature caterpillar of *S. littoralis* [x 3.5]

Source: Berg and Cock, 2000

All stages of the larvae of *S. littoralis* almost always fed on the head of the developing cabbage where they were embedded (Plate 5.11). Sometimes force was required to remove them out. Younger caterpillars might also be found on the underside of leaves up to about 6 days after hatching. Their feeding was associated with dark brown wet faeces on cabbage.



**Plate 5.11: Larva of *S. littoralis* [x 2.0] (arrowed)
feeding on cabbage head**

In the laboratory, pupation took place after the pre-pupal cuticle had been shed. They shortened, and shed the pre-pupal skin one day before pupating. No cell or pupal case was formed. The dark brown pupa ranged in length from 15 - 19 mm, and had a pair of spines at the posterior tip (Plate 5.12).



Plate 5.12: Pupa of *S. littoralis* [x 5] spine arrowed

The adult is a brown to dark brown medium sized moth with white markings. Dark to blackish markings were also present on the wings (Plate 5.13). The body length ranged from 15 - 19 mm and wing span ranged from 36 - 41 mm.



Plate 5.13: Adult of *S. littoralis* [x 2.7]

Source: Berg and Cock 2000

5.3.1.4 *Helicoverpa armigera* (Hübner)

Eggs of this species were not encountered in the field during the present study. The caterpillar was robust and very intense green in colour and grew up to 39 mm long. The head is brownish and there was a white or pale yellow band along the ventro-lateral side of the body (Plate 5.14a, b). Five pairs of legs were present on the abdomen including a pair at the abdominal tip. Segmentation is very pronounced (Plate 5.14b). There were three (appearing as one) dark greenish longitudinal stripes on the dorsal surface and a pale yellow band on each lateral side of the body. There was another pale thin lateral band above the dark greenish band. In each pale yellow band, there was a set of spiracles and one small black spot per segment. Each of these black spots also had a strand of hair (Plate 5.14b) extending from it. The last abdominal segment had a black patch, which slightly expanded towards its posterior side. Each of these expanded portions had a tubercle with a strand of hair protruding from it. On the dorsal surface of the caterpillar there were two pairs of tubercles each with a hair strand. A pair was located on either side of the mid dorsal dark greenish stripe. As the larvae mature, the colour remained green or became variable and changed to brown, coffee brown or very dark reddish brown with two black spots near the anterior end of the body and the abdominal tip. Colouration of the bands became more intense before moulting.



**Plate 5.14a: Larva of
H. armigera [x 1.5]**



**Plate 5.14b: Larva of
H. armigera [x 1.7]**

Source: Berg and Cock, 2000

Caterpillars of *H. armigera* always bored deep into the growing point of the cabbage during cupping where they fed and subsequently killed it. The feeding typically caused rotting or formation of multiple heads. They moved from plant to plant after damaging the growing tips. There was no occasion when they were found on any other part of cabbage or more than one caterpillar per plant. The presence of this pest could be detected by yellowing of buds and the presence of faeces around the growing points.

In the laboratory, the mature caterpillar chewed leaf tissue to construct a cell and shed off the pre-pupal skin before pupating in the cell. The pupa was brown in colour and had a spine at its posterior end.

The adult is a robust moth and varied in colour from dull brown or greenish to buff or brownish orange. There was a characteristic dark spot towards the anterior margin of each forewing and a slightly wavy dark and pale band (Plate 5.15).



Plate 5.15: Adult of *H. armigera* [x 2]

5.3.1.5 *Hellula undalis* Walker

Eggs of this species were not encountered in the field. The caterpillar was small and pale pinkish, brownish or dirty green, with characteristic dark reddish or pinkish longitudinal thin stripes on the body (Plate 5.16). The two stripes on the dorsal surface were more pronounced. There were ten black spots on each segment, with three on each lateral side and four on the dorsal surface. It had a small blackish head and a black shiny thoracic shield which turned pale as it matured. Mature larvae grew up to 14 mm long.



Plate 5.16: Larva of *H. undalis* [x 2.2]

The caterpillar was usually found in the developing bud at the nursery and pre-head formation stages. They fed on the bud and typically spun lots of web around themselves. This webbing associated with them could be used to detect their presence. The webbing and frass completely surrounded the growing point of the plant to the extent that it could not grow. When the caterpillars were not in the bud they scraped the epidermis, leaving a thin area on one side. They might also be found on the ventral side of the lower margins of leaves near the leaf bases. In this location, they rolled the leaf using a whitish silken thread. Only one caterpillar was ever found in a leaf roll. Their black faeces lined the rolled leaf and this could also be used to detect their presence. Damage by *H. undalis* to the developing bud usually killed the plant or led to multiple head formation.

Prior to pupation, the mature larva spun a thick web for two days and prepared a cell from a white transparent silken thread in the tissue paper, which lined the rearing jar. The shiny light brown pupa was between 7 - 10 mm long.

The adult is a small, sandy light brown or brown moth with pale wavy transverse bands on the wing in the resting position (Plate 5.17). Old specimens lost these bands and the insect then generally looked pale. There was a characteristic pair of blackish spot or eyes toward antero-apical forewing. The length of the adult was between 7 - 8 mm and it had a wing span of about 17 mm.



Plate 5.17: Adult of *H. undalis* [x 3.6]

5.3.1.6 *Spoladea recurvalis* (Fabricius)

Eggs of this species were not encountered on cabbage. The larvae and adults were more associated with the weed *Cyperus rotundus*. When on cabbage, the larvae were found in the inner side of young cabbage leaves and wriggled backwards violently when disturbed. The caterpillar is small, pale, greenish and transparent. The head was brownish and there was a thoracic shield. It had four pairs of abdominal legs with an additional two pairs at the abdominal tip. The mature caterpillar grew up to 15 mm long. Before pupation, it turned bright pink. The pupa was small and pale

brown and measured 9 - 10 mm long. In the laboratory, pupation took place in a white transparent cell.

The adult is a small, dark brown moth of about 13 mm long with a wing span of about 19 mm. The forewing had a pale or white, vertical band around the mid portion and a smaller one near the apex, but not reaching posterior margin (Plate 5.18). There were also pale longitudinal bands on the dorsal side of the abdomen. The ventral side was pale, with no bands.



Plate 5.18: Adults of *S. recurvalis* [x 2.0]



5.4 Discussion

This study has provided detailed descriptions of the stages, nature of damage and the specific niches of the Lepidopteran pest complex of cabbage under field situations in Ghana. All parts of the cabbage plant were utilized by one or more of these pests. Most of the existing literature (Talekar and Griggs, 1986; Talekar, 1992; Youdeowei, 2002; Obeng-Ofori *et al.*, 2007) gave brief descriptions without illustrations on the nature of the damage, behaviour or recognition in the field. The diamondback moth,

P. xylostella was the ubiquitous pest occurring from the nursery through to crop maturity and occurred on all parts of the cabbage plant.

The habit of *P. xylostella* females laying their eggs in depressions or close to leaf veins on the ventral surface rather than on the dorsal surface may have some ecological significance. The micro-climate in these habitats may be more favourable for development and may also protect the eggs from being easily washed away by rain. In the laboratory, the observed preference for laying eggs on the lower part of leaves could support the above suggestion. This may also be a specific niche requirement since this species occurs together with *T. ni*, the eggs of which, apart from being different in shape, were also laid on the ventral surface. Use could also be made of this specific niche characteristic in field identification of eggs of the two species.

The results of the present study indicate that the first instar larvae of the diamondback moth simply buried their heads whilst feeding and were not leaf miners as reported from previous studies (Talekar, 1992). Hardy (1938) observed that when the diamondback was provided with very tender leaves, they did not exhibit this characteristic.

Dobson *et al.* (2002) noted that the female *P. xylostella* moth lacked the characteristic pale diamond shape on the dorsal surface of the wing. However, observations on the Ghanaian specimens showed otherwise. The lighter colour of the females make the diamond shaped patterns less conspicuous.

The observation that *Hellula undalis* feeds on the developing bud of cabbage in the nursery as well as in the field supports the recommendation by (Obeng-Ofori *et al.*, 2007) that control of the pest should start early in the season. In addition, the webbing associated with the pest as it feeds obstructs normal growth of cabbage. *Spodoptera littoralis* and *H. armigera* were considered occasional pests by Brown (1975); Talekar (1992); Waterhouse (1992), Berg and Cock (2000). In the case of *S. littoralis*, because of the very large numbers of eggs laid by a single female and the dispersal behaviour of the young caterpillars after the first moult on the plant, and the fact that they fed on the growing point, could make them damaging to cabbage when they occur on it. On the other hand, *H. armigera* has been classified by Rowell *et al.* (1992) and Poelking (1992) as minor or a seasonal pest. However, they can be damaging even in low numbers considering their behaviour of moving from one plant to the other after destruction of the growing tip of the cabbage which led to rotting.

The descriptions and illustrations provided in this study will undoubtedly aid in field recognition and identification of the pests and a better understanding of their behaviour. It would also allow an informed decision to be made on the spray equipment and targeted application of insecticides in an Integrated Management Programme on cabbage. The results would also complement the observations by Youdeowei (2002) and Obeng-Ofori *et al.* (2007) as a comprehensive contribution to research on sustainable production of cabbage in Ghana.

CHAPTER SIX

6.0 DESCRIPTION OF PARASITOIDS OF THE LEPIDOPTERAN PESTS OF CABBAGE

6.1 Introduction

The most important parasitoids used in biological control and integrated pest management methods against insect pests occur in the order Hymenoptera (CAB International 1994; Pratisoli *et al.*, 2008). Fundamental in the development of an integrated pest management programme is the correct identification of the insect pest involved and its principal parasitoids (Kumar, 1984; Dobson *et al.*, 2002). Of the components of integrated pest management, it is biological control which emerges as the least understood because of the difficulty of understanding the taxonomy of parasitoids (Waage and Greathead, 1992; Bio-NET International Business Plan, 2007-2010). Despite the importance of the parasitoids, their taxonomy in most regions remain poorly known and their identification is difficult or impossible (Goulet and Huber 1993; Bio-NET International, 1999; La Salle, pers comm.). The minute size of most of them especially the Chalcidoidea, makes their study unattractive (Boucek, 1988). Since there can be no meaningful basic or applied entomological research until the identity of the organisms involved have been determined (Waage and Greathead, 1986; Jones, 1994; Consortium for the Barcode of Life, 2009), taxonomic knowledge is greatly needed, especially with projects on control of pests, host parasitoid relations, and environmental or faunal studies (Ritchie, 1985; Bio-NET International, 2006; Smith *et al.*, 2008).

Most of the available keys to parasitoid species have been provided for Europe, North America and the Oriental Region (Ferriere, 1929; Burks, 1960, 1965; Riek, 1967; Joseph *et al.*, 1973; Boucek, 1988; Narendran, 1989). Unfortunately, in Africa, there are either no keys or descriptions and the available keys are out of date and cannot be used, thus making identification and recognition of species from this region difficult or impossible (LaSalle, CABI Bioscience Pers. Comm.). The situation is particularly serious due to lack of references on African entomo-fauna in general, and particularly on the parasitic Hymenoptera, which contains most of the parasitoids (Risbec, 1951; Risbec, 1960; Boussienguet and Neuenschwander, 1989; Gupta, 1991). Other problems are the lack of access to type materials and inadequate descriptions without illustrations (Boucek, 1988). This Taxonomic Impediment is particularly acute in the developing countries (Bio-Net-INTERNATIONAL 2006; Smith *et al.*, 2008).

Taxonomic characterization of local populations of parasitoids is of crucial significance in biological control and need to be explored thoroughly if maximum benefits are to be expected (Salinas, 1986; Ooi, 1992). In some cases the overreliance on identification and taxonomic decisions made by museum workers and the fact that specific strains of parasitoids may be associated with specific strains of pests native to different countries, have probably restricted biological control research (Fitton and Walker, 1992; Sarfraz *et al.*, 2005). Thus, for effective exploitation and utilization of the parasitoids associated with the major lepidopterous pests of cabbage in Ghana, it is crucial that their identities and, especially, their characteristics are documented and understood.

The objective of this study therefore, was to describe and provide illustrations of the parasitoids observed and identified from the Lepidopteran pests on cabbage in southern Ghana.

6.2 Materials and Methods

6.2.1 Identity and Description of Parasitoids

The parasitoids and hyperparasitoids were described based on specimens collected and observed from the pests at the experimental site and parts of Ghana. For the dominant parasitoid species *C. plutellae*, 25 individuals of each sex were studied whilst for the gregarious ones such as *Euplectrus laphygmae*, *Oomyzus sokolowskii*, *Pediobius* sp. *Tetrastichus atriclavus*, *Aphanogmus reticulatus*, and *Elasmus* sp., the progeny from several hosts were pooled together. The number studied for each species therefore varied depending on availability.

The terminologies and classification adopted by (O'toole, 1986; Boucek, 1988; Goulet and Huber, 1993) were followed. The antennae and fore wings yield useful characters which are important in identification (Boucek 1988; Goulet and Huber, 1993). Particular attention was therefore paid to these. Where possible, comparisons were made with known and related species.

Illustrations were made using a Nikon microscope attached to a Camera Lucida/drawing tube, Scanning Electron Microscope, Photomicroscopy, and a Digital Camera. Measurements were done on a Nikon microscope fitted with 10 mm. micrometer in the eye piece and later converted. Diagrams to explain the terminologies used are illustrated in Plates 6.1a and 6.1b.

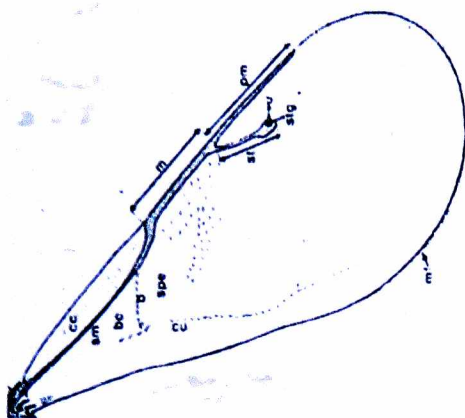


Plate 6.1a Wing illustration
of terminologies

m = Marginal vein
 pm = Post marginal vein
 sm = Submarginal vein
 un = Uncus
 st = Stigmal vein
 stg = Stigma

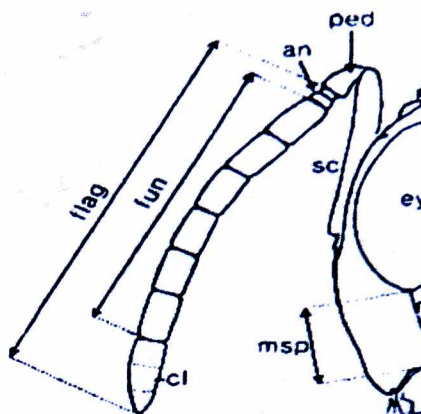


Plate 6.1b Antenna illustration
of terminologies

flag = Flagellum
 fun = Funicle
 an = Anellus
 cl = Club
 ped = Pedicel
 sc = Scape

6.2.2 Scanning Electron Microscopy

Scanning electron microscopy of specimens of *C. plutellae* was done at the Entomology and Nematology Department Gainesville, University of Florida USA. Specimens preserved in 70% alcohol were removed and dried in a dessicator for four days. A special sticker was placed on each stub and the specimen was carefully placed on it to allow rotation at all angles. Each stub had only one specimen placed on it. The specimens were then placed in a vacuum window of the Sputter Coater (Denton Desk 2 model) for five minutes to ensure that they were thoroughly dried. After this, they were coated with gold for three minutes. The stubs were then turned onto their sides with a pair of curved forceps and coated with gold for three minutes and a further two minutes making a total of eight. The duration of coating, however,

depended on the size of the specimen to be scanned. They were then transferred into a specimen holder and placed in a dessicator till they were ready for scanning electron microscopy.

A Polaroid Positive - Negative 4 x 5 Instant Sheet Film was used. After processing the photographs, the negatives were separated from the print and immediately cleared in Sodium sulphite solution for about four minutes and then drained for a few seconds. They were then washed in running water for about five minutes after which they were hung to dry for later printing using conventional techniques. The prints were immediately coated after processing to protect them against scratching and fading. The coating was applied to the prints including the borders, in six to eight overlapping strokes to ensure entire coverage. They were kept separately from each other on a flat surface until they were thoroughly dry.

6.2.3 Photomicroscopy

Different methods were used for dry specimens and wet specimens i.e. those that could not be taken dry because the cuticle collapsed when out of the preservative.

The photographs of the wet specimens (preserved in 70% alcohol) were taken on an Olympus OM2 Macro Photography System using extension bellows. The system was fitted with a macro 38 mm lens and set at F 22 or F16 with Olympus T10 flash ring. This system allowed the photographs to be taken through liquid. An ordinary daylight film was used. The specimens to be photographed were taken out of alcohol and thoroughly cleaned after which they were placed in alcohol in a glass stage prepared from a petri dish and a rectangular piece of clear glass. The alcohol level in the stage

was such that no meniscus occurred between the specimen and the alcohol level since that would interfere with the reflection of the specimen. It was also necessary not to use too much alcohol as this would cause the specimen to float. Photographs of the dry specimens were taken with a microscope fitted with an Olympus camera.

6.3 Results

6.3.1 Identity of the Parasitoids

Thirteen species of Hymenoptera and two species of Diptera were identified as parasitoids and/or hyperparasitoids of the pests on cabbage (Table 6.1). Seven were identified to species, two to species groups and the rest to generic level.

Table 6.1 Identity of the Parasitoids / Hyperparasitoids Recorded from the Lepidopteran Pests on Cabbage

Superfamily	Family / Subfamily	Species
Ichneumonoidea	Braconidae / Microgastrinae	<i>Cotesia plutellae</i>
	Braconidae / Cheloninae	<i>Chelonus curvimaculatus</i>
	Ichneumonidae	<i>Charops</i> sp.
Chalcidoidea	Chalcididae / Brachymerinae	<i>Brachymeria</i> sp.
	Chalcididae / Haltichellinae	<i>Hockeria</i> sp.
	Elasmidae	<i>Elasmus</i> sp.
	Eulophidae / Eulophinae	<i>Euplectrus laphygmae</i>
	Eulophidae / Tetrastichinae	<i>Oomyzus sokolowskii</i>
	Eulophidae / Tetrastichinae	<i>Tetrastichus atriclavus</i> s. l
	Eulophidae / Entedoninae	<i>Pediobius</i> sp.
	Eulophidae / Eulophinae	<i>Notanisomorphella</i> sp **
	Pteromalidae / Pteromalinae	<i>Trichomalopsis</i> sp.
Ceraphronoidea	Ceraphronidae	<i>Aphanogmus reticulatus</i>
Muscoidea	Tachinidae	<i>Blepharella curvimaculatus</i>
	Tachinidae	<i>Peribaea orbata</i>

** *flaviventris* group.

6.3.2 Descriptions of the Parasitoids

6.3.2.1 Ichneumonoidea

Cotesia plutellae (Kurdjumov) = *Apanteles plutellae* Kurdjumov (Braconidae)

Both sexes of *C. plutellae* are similar in general appearance. They are black but the female has slightly pale brown lateral areas (not very sclerotised) on the antero-dorsal abdomen (Plate.6.2). The lateral areas vary in intensity of the colouration or sclerotisation. The gaster is shorter than the mesosoma. The anterior three quarters of the sternum of the female gaster is brownish (lightly sclerotised) with the remaining posterior part black. This lightly sclerotised part often collapses when the specimen dries up. Venation of the forewing is well developed, but the apical veins are nebulous (faint). A strong pigmented spot is present about two-thirds towards the anterior margin of the fore wing (Plate 6.2 arrowed).

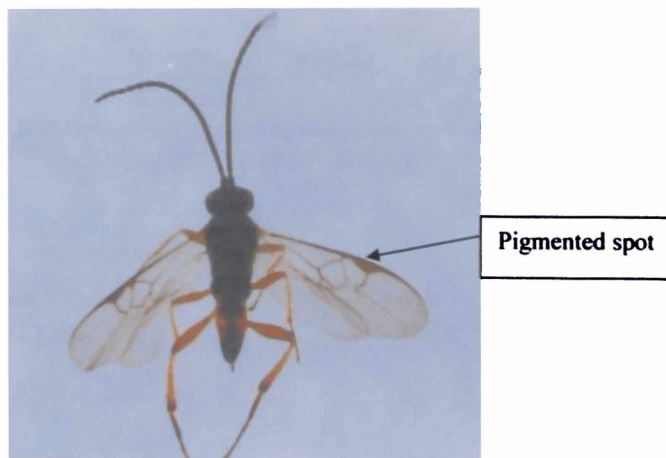


Plate 6.2: Female *Cotesia plutellae* [x 13]

In the males the dorsal part of the entire abdomen is usually black. Only a small portion of the anterior part of abdominal sternum is lightly sclerotised. As a result the females appear generally lighter coloured. Apart from the ovipositor, this can be used to easily separate the males from females. The legs are hairy and uniformly brownish except the hind femur and tibiae which have dark apices. A trochantellus is present

between the coxa and the trochanter. The mid and hind tibiae have two apical spines, the inner one being the shorter of the two. There are five tarsal segments. Tarsal segments of the hind-legs are darker than those of the fore-legs and the mid-legs. First tarsal segment is the longest of the tarsal segments. Vein 2-M of fore-wing is nebulous. Vein 1r-m of hind-wing is more or less basal of SC+R (Plate 6.3).

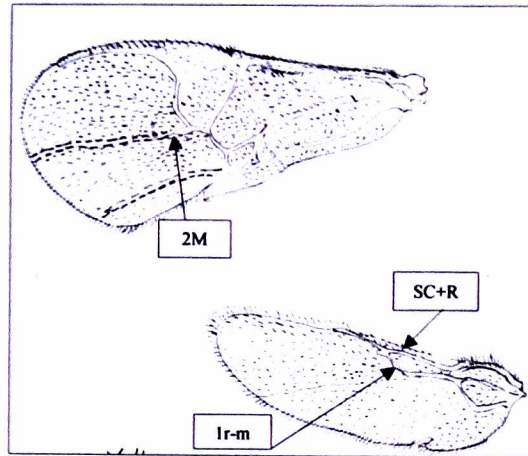


Plate 6.3: Schematic diagram of fore-wing and hind-wing of *C. pluteillae* [x 17]

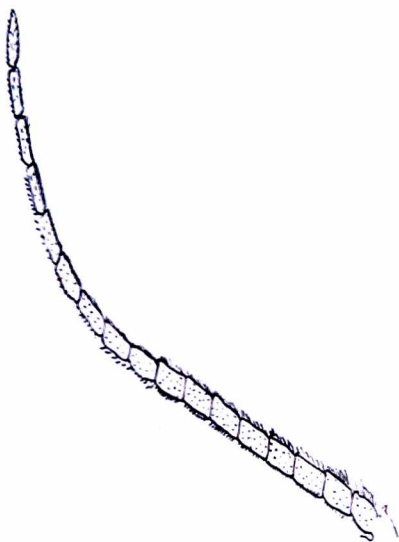
Key

2M = Second Median Vein

SC+R = Sub-Costal and Radial Vein

1r-m = Vein joining the Radial and Median vein

Significant differences exist between male and female with regard to body measurements of *C. plutellae*. The average length of female is 2.49 ± 0.02 mm and that of the male is 2.16 ± 0.02 mm. Abdominal width is 0.46 ± 0.03 and 0.49 ± 0.03 mm for males and females respectively. The antenna is made up of 17 segments plus a radicle (Plates 6.4a, b). The scape is bulbous but the rest of the segments are elongated and similar in length.



v ii

Plate 6.4 a: Schematic diagram of antenna of male *C. plutellae* [x 20]

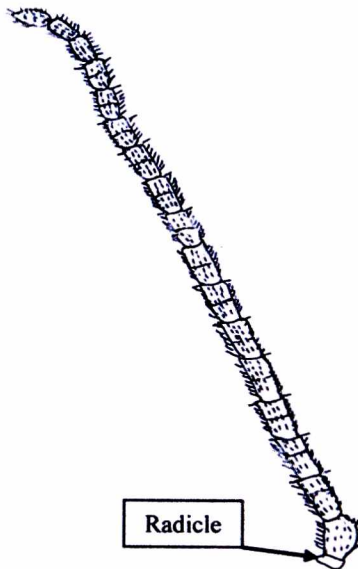


Plate 6.4 b: Schematic diagram of antenna of female *C. plutellae* [x 20]

The Scanning Electron Micrographs showed that sexual dimorphism exists in the length and hairiness of segments of the antennae (Plates 6.5a, b). The male segments have longer and denser hairs than in the females. In addition, the apex of the last segment is blunt in males whereas it is pointed in the females. In both sexes there is a pair of conspicuous stiff hairs at the apices.



Plate 6.5a: Scanning electron micrograph of female antenna [x 240]



Plate 6.5b: Scanning electron micrograph of male antenna [x 300]

The frons, including the genae, are very hairy with the former being wider than long. The vertex is especially very hairy (Plate 6.6). The clypeus is broad and the margin curves inward at the middle. Malar sulcus is present at the malar area. An anterior tentorial pit is conspicuously present on either side of the clypeus. The antennae articulate with the head high above the clypeus.

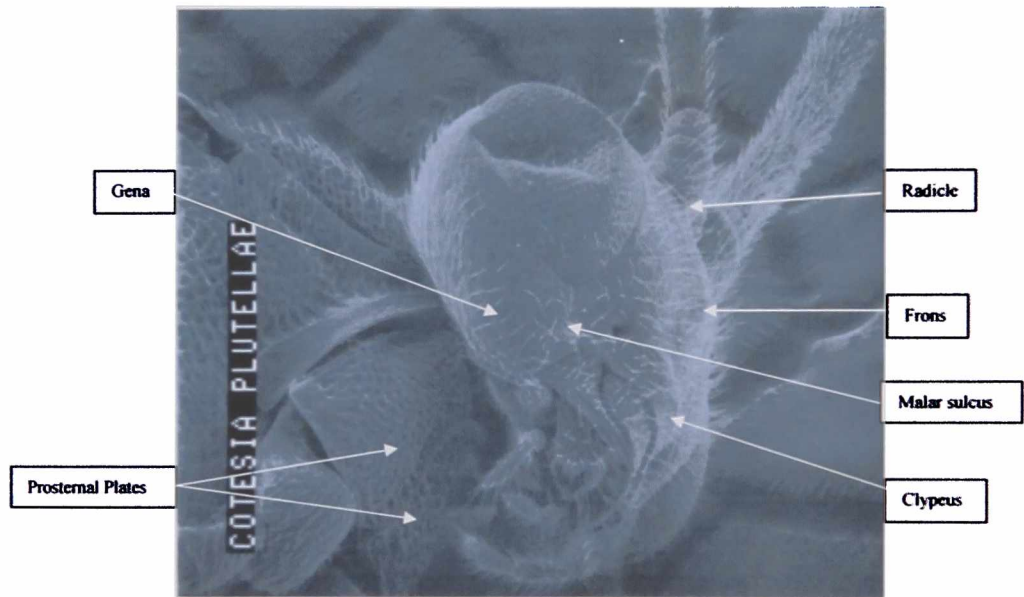


Plate 6.6: Scanning electron micrograph of facial view of *C. plutellae* [x 110]

The mesosoma has various punctures and striae on the dorsal surface. The pronotum is not well developed but the prosternum is made up of two large sculptured plates (Plate 6.6). The mesoscutum has a higher concentration of hairs than on the other nota (Plates 6.7a, b). Well developed tegulae are present. The scutellum has a distinct slightly raised triangular mid portion surrounded by well developed striae. A

deep sulcus is present on either side of the scutellum. The posterior margin of the scutellum is deeply convex. The metanotum has two rounded sulci at the mid anterior margin (Plate 6.7a). On either side of each sulcus a row of striae is present. The pleural side of the thorax (mesosoma) is much smoother. The mesopleuron has three plates/sclerites, a smaller anterior triangular piece and a bigger posterior more or less rectangular piece. A much smaller piece joins these two. The triangular piece has a row of striae about one third way up from the longer side (Plate 6.7b). On the larger sclerite a row of deep punctures occur along the upper and right lateral margins. Another faint row of punctures extends from the left side but becomes faint as it joins the right lateral margins. The propodaeum is heavily punctured.

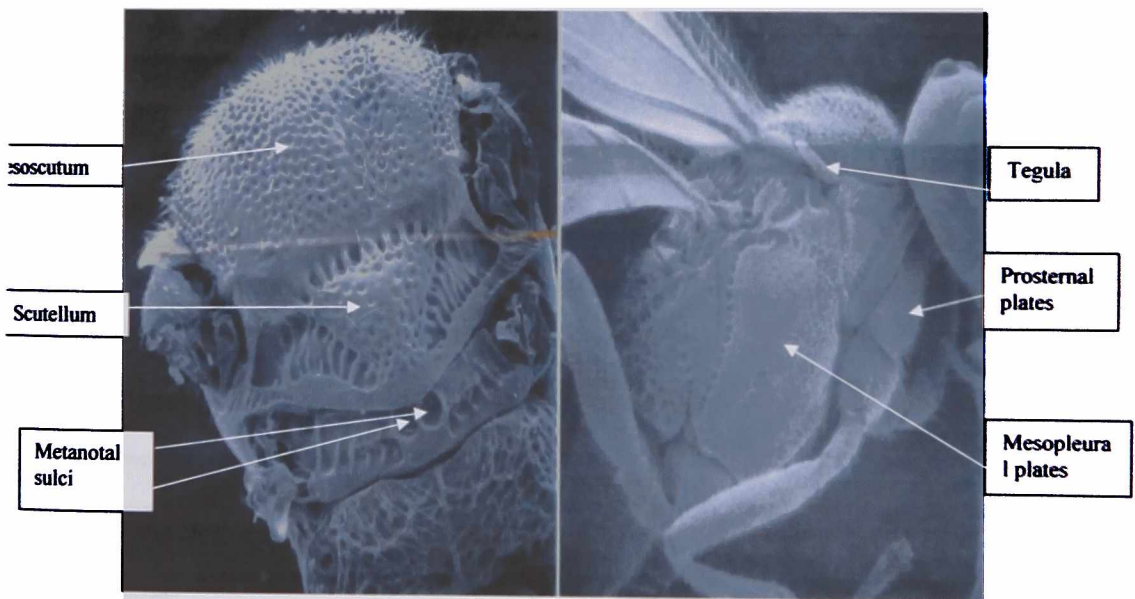


Plate 6.7a: Scanning electron micrograph dorsal view of mesosoma [x 90]

Plate 6.7b: Scanning electron micrograph lateral view of mesosoma [x 66]

***Chelonus curvimaculatus* Cameron (Braconidae)**

It is a medium size parasitoid measuring 5.5 mm long. The body has a dense mat of short pale hairs and a long (at least 27 segments) black antenna of about 3.5 mm in length. The head and thorax are black and highly punctate. It has three Ocelli, with dark brownish eyes. The antennae arise high above the clypeus on the vertex (Plate 6.8b) and almost between posterior ends of eyes. The fore leg is very short, and the coxa and trochanter are black. The basal part of the femur and the last tarsomeres are dark, but the rest of the fore-leg is pale brown. A curved tibial spur is present. The mid-leg is long and has a black rounded coxa covered with a dense mat of hairs. The trochanter is about as long as the coxa. The basal half of the mid-femur is slightly dark and the apical half is pale brown. The tibia has two apical spurs which are not curved. The hind-leg is the longest, and the femur is well developed and appears swollen. The hind coxa is not as rounded as it is in the mid coxa. The coxae, trochanter and femur are black. The apical half of the tibia is very dark. There are two apical tibiae spines of unequal lengths.

Metasomal terga 1-3 are fused and form a carapace (Plates 6.8a, b) which covers the remaining terga. The tip of the carapace is rounded and curves ventrally, as a result of which the apex of the abdomen is concealed. The carapace is black and has a pale anterior dorso-lateral bands which do not touch each other in the middle of the dorsum. The anterior-most part of the carapace is black but the lateral margins are slightly pale. There is an equivalent pale creamy band on the sternum of the metasoma. The first tarsomere is the longest in all the three legs.



Plate 6.8 a: Adult *Chelonus curvimaculatus* [x 4.0]

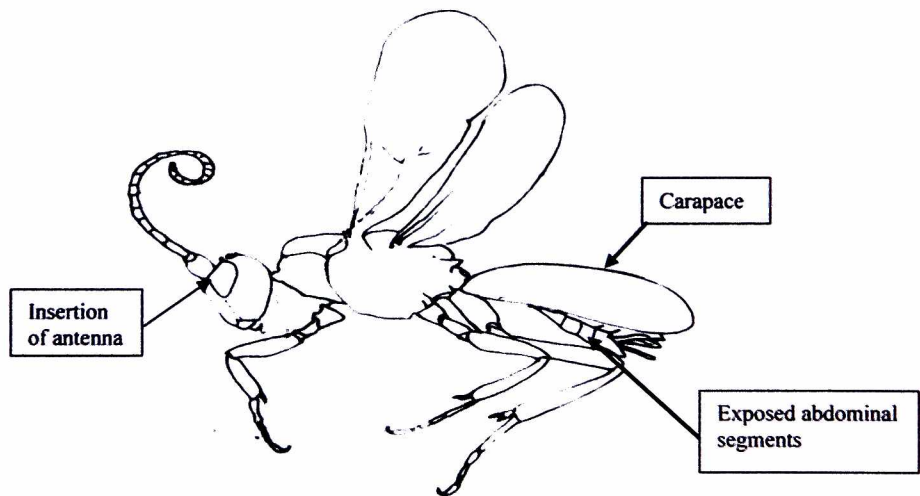


Plate 6.8 b: Schematic diagram of *C. curvimaculatus* [x 15] to show carapace

Source: Goulet and Huber, 1993

***Charops* sp. Ichneumonidae**

This is an elongated dark parasitoid. Length of male is 9.67 ± 0.13 mm. Female is 13.16 ± 0.31 mm long including the ovipositor. The thorax and propodeum (mesosoma) are highly sclerotised and punctate (Plate 6.9). Head is lenticulate (antero-posteriorly depressed) with very long antennae almost as long as the fore wing (Plate 6.9). Fore and mid legs creamish or pale except tarsi which are dark. Hind legs are dark and two tibial spines are present at apices.

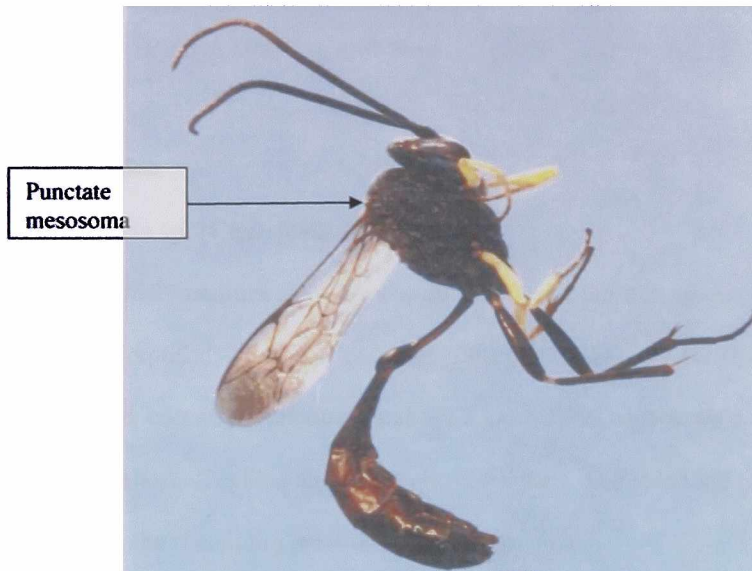


Plate 6.9: Female *Charops* sp. [x 7.0]

Venation is well developed and complete, fore wing with vein 2m-cu tubular in part (Plate 6.10). Hind-wing with vein 1r-m distally of distal end of vein SC+R.

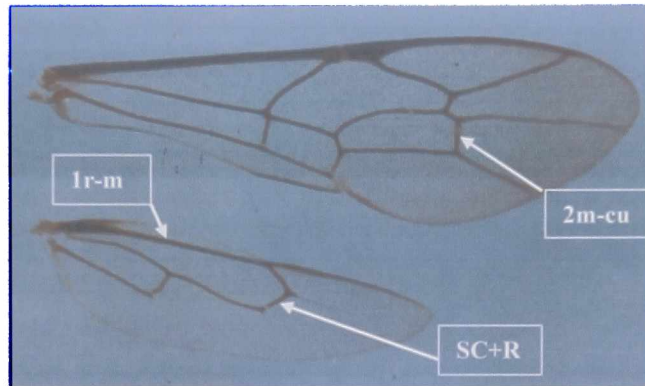


Plate 6.10: Fore and hind wings *Charops* sp. [x 16]

6.3.2.2 Chalcidoidea

***Brachymeria* sp. (Chalcididae)**

This is a black medium sized parasitoid measuring 5.5 mm long. The entire body is heavily sclerotised; head and mesosoma especially heavily punctate. Mesosoma is convex and coarsely punctured and with numerous conspicuous short hairs. The antenna is short. Tegulae and tibiae are yellowish. The proximal part of the femur is black, with the remaining parts of the leg pale.

The hind femur is greatly enlarged, compressed and almost oval shaped (Plate 6.11). It is about 2 times as long as wide and ventrally dentate with eight teeth. The proximal five teeth are more developed and widely spaced, but the remaining ones are closely spaced and smaller. There is a row of white hairs along the ventral part of the hind femur. The hind tibia is distinctly curved and has a groove into which the femur fits or locks at rest. The apices are truncate and slightly pointed at one side. The fore

and mid legs are similar in size and colouration. The propodeum has some alveoli on the anterior part and a median carina. The ovipositor is very thick and extends slightly beyond the tip of the abdomen. The first gastral tergite is enlarged, and it is almost as long as the rest of the gastral segments together.

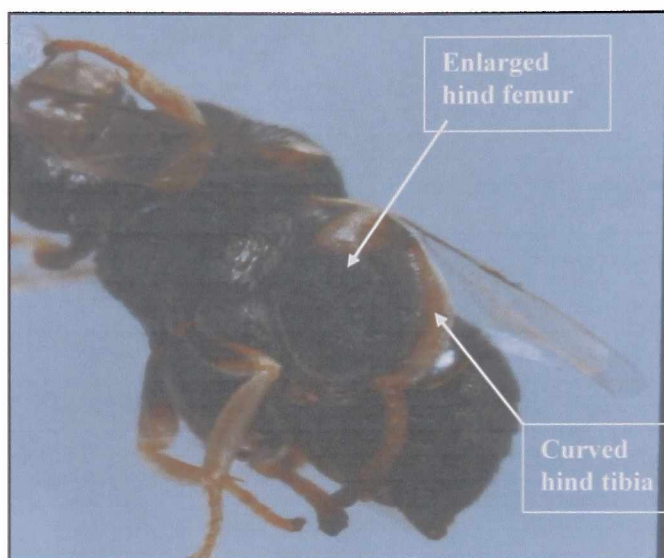


Plate 6.11: Female *Brachymeria* sp. [x 20]

***Hockeria* sp. (Chalcididae)**

This is a medium sized black Chalcid of length 2.2 mm for males and 2.3 - 2.4 mm for females. It is ant-like in appearance with relatively long legs and is not active. The body is very punctate and highly sclerotised. It has large eyes which are pale. The coxae are black, hind femur black and enlarged with spines at the apex. There is a long curved groove on the inner side of the tibia into which the femur fits when at rest. The hind tarsus is brownish, apex of mid femur thickened or swollen and darker than rest of the leg segments which are brownish. The first tergite of the gaster is longer than twice the remaining ones put together (Plate 6.12). The posterior tergites of the gaster are short and overlap or appear to telescope into each other. The gaster

is more or less convex and slopes forward. The ovipositor is stout and extends slightly beyond the tip of the gaster.

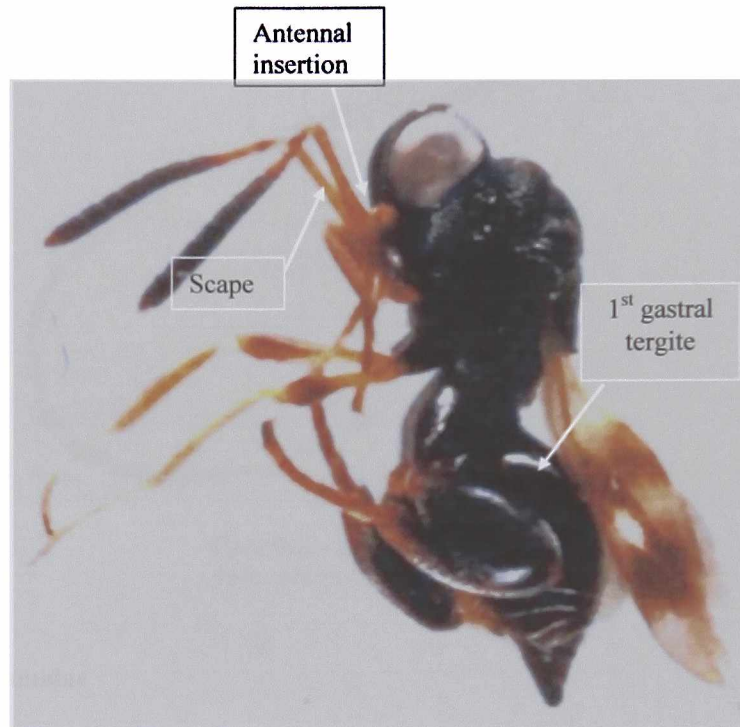


Plate 6.12: Female *Hockeria* sp. [x 40]

It exhibits sexual dimorphism in the antennae. The antennae arise very close to the clypeus, elbowed and twelve segmented. In both sexes the scape is very long. In the male, the scape and pedicel are dark brownish with the remaining ten black. In the female, the scape, pedicel and first segment of the flagellum (flagellomere) are distinctly light brownish with the remaining black (Plate 6.12). The wings have two wide dark vertical bands on them. The stigmal vein is very short, postmarginal vein is shorter than marginal vein (Plate 6.13).

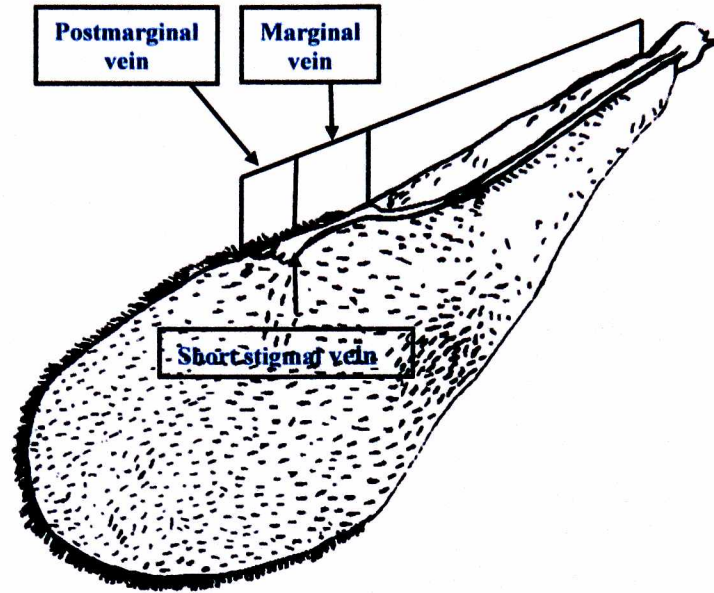


Plate 6.13: Schematic diagram of fore-wing of *Hockeria* sp. [x 40]

***Elasmus* sp. Elasmidae**

Female

The female of this species is bigger than the male. It is slim and elongated and measures 3 mm in length. It is distinctly brightly coloured orange and black (Plate 6.14). The head is lenticulate (depressed), yellowish, black setose vertex and frons. Malar area groove is not well defined. The eyes are well developed and conspicuous and pale with a tinge of mauve or pink, and surrounded by darkened area. The pronotum is black dorsally but the pro-sternum is orange. The Meso - scutum is orange with black transverse bands, heavily and conspicuously setose. The posterior margin of the meso-notum has a blackish transverse band narrower in the middle but wider under the fore wing bases. There are two very conspicuous setae at inner base of wing, and another pair at outer base of wing. Tegulae black and well developed. The

meta-notum is yellowish and black with two conspicuous setae. It extends backward such that the propodaeum is not easily visible; petiole transverse making the joint between it and rest of gaster appear broad, somewhat like that of a sawfly (Symphyta). The propodaeum is emarginated postero-laterally. This species is shaped like a keel or wedge (Plate 6.14). The legs are uniformly pale brown coloured with dark margins. The gaster is elongated and pointed at the apex (ovate), dorsal surface flattened, posterior segments with dorsum black. The ovipositor is short and extends slightly beyond apex of abdomen

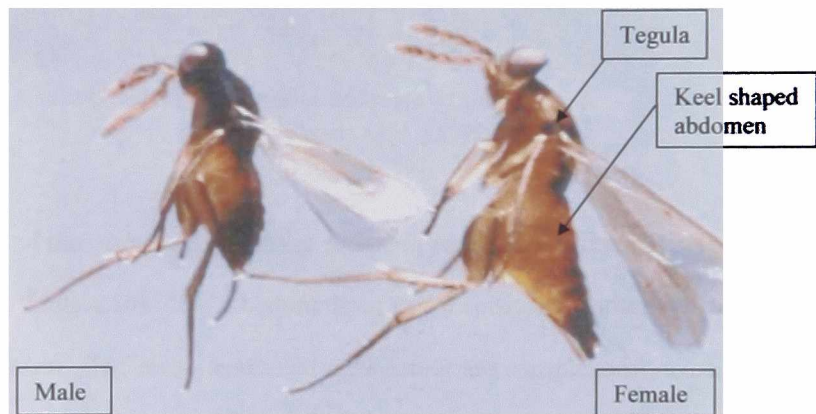


Plate 6.14: Adult male [x 17.5] and female [x 16] *Elasmus* sp.

The antennae of the female are brownish orange and hairy and arise very close to the clypeus. They are nine segmented. There are seven flagellomeres (Plate 6.15) made up of one small anellus, 3 segmented funicle and a three segmented club. The apical segment of the club is narrower than other two. The basal segment of the funicle is slightly narrower than the other two (Plate 6.15). The pedicel is about 2 ½ times the length of the scape. A conspicuous radicle articulates with the torulus.

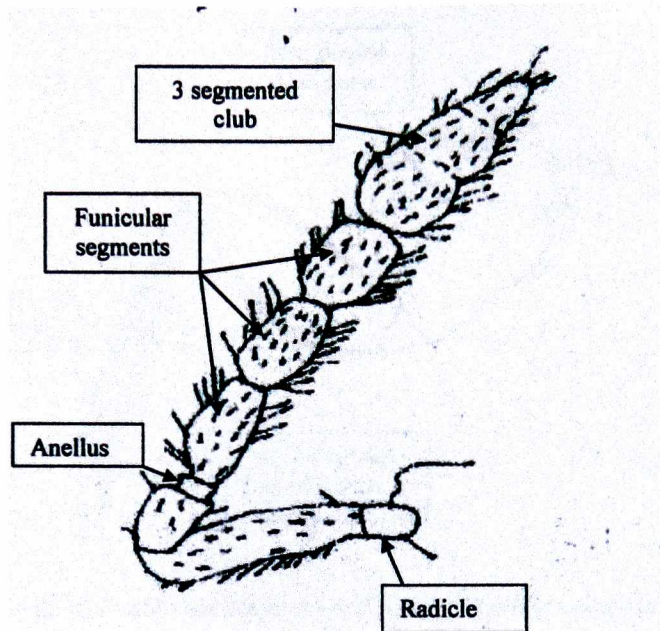


Plate 6.15: Schematic diagram of antenna of female *Elasmus* sp. [x 120]

The hind coxa of this species is very large and compressed like a disc and appears flat in lateral view (Plate 6.16). It is accommodated in the emarginate postero-lateral part of the propodeum. The meso-femur and meta-femur are conspicuously compressed and elongate oval. The meso-tibia has a sub apical spine. The meta-tibia also has a very long sub-apical lobe-like setae and a smaller one. In addition the meta-tibia has diamond shaped patterns formed by a dense row of conspicuous flattened, short black bristles (Plate 6.16) arranged in a continuous line which loops back on itself to form apparently closed cells. In latero-dorsal view, seven of the bristles, of which two are bigger than the rest, are clearly visible. In lateral view only four are visible. The tarsus has four tarsomeres and in lateral view is uniformly pale, narrow and elongate. The first tarsomere is the longest.

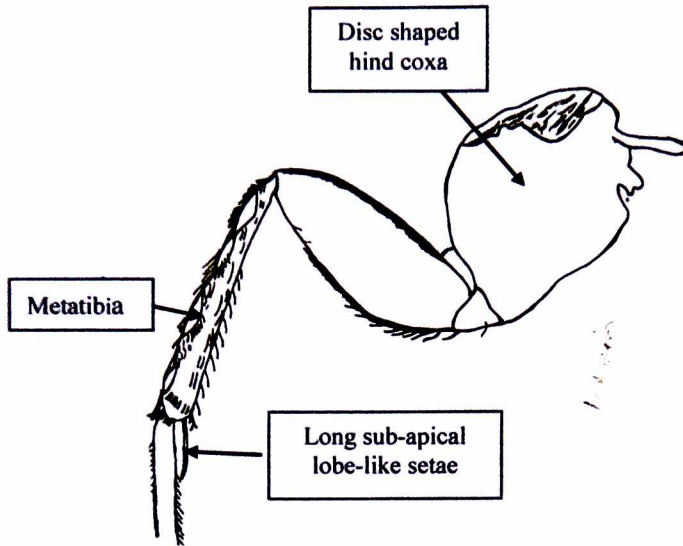


Plate 6.16: Schematic diagram of hind leg of *Elasmus* sp. [x 55]

Venation is greatly reduced. The forewing is densely setose (has numerous short hairs) over a pale brown background, and is distinctly elongate and narrow with a rounded apex (Plate 6.17). The sub-marginal vein is longer than the post-marginal vein. The marginal vein is very long, post-marginal vein short, stigmal vein sessile and pale. A dense row of short hairs occurs at the apex of the wing (Plate 6.17). The length of the wing is about three and half times the greatest width.

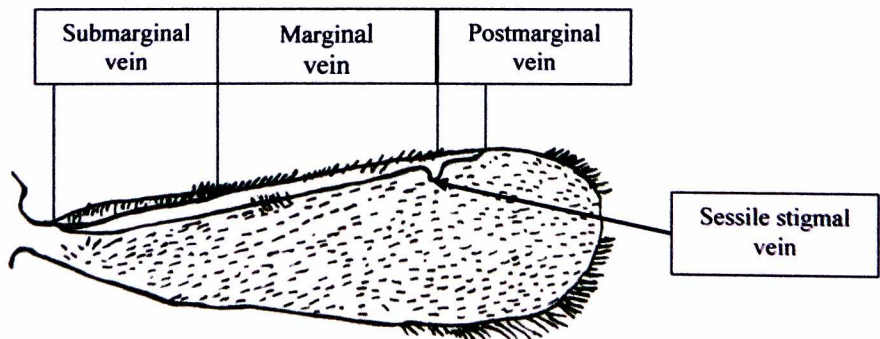


Plate 6.17: Schematic diagram of forewing of female *Elasmus* sp. [x 40]

Male

The male is smaller (2mm) and dull coloured with black and brown metasoma (Plate 6.18). Head and face are black and setose. Mesosoma is black, except meso-sternum and distal parts of coxae. Antenna is moderately long, branched (Plate 6.18) and ten segmented. The antenna has a broad scape, short pedicel and eight flagellomeres: a small ring-like annellus, four segmented funicle and three segmented club. Three long lateral hairy extensions (rami) arise from the three basal funicular segments thus making it appear like a feather. Apical segment of club of flagellum tapers to a point.



Plate 6.18: Adult male *Elasmus* sp. to show branched antennae [x 30]

Head and Mesosoma are black, metasoma (abdomen) dark and brownish orange. Posterior 2/3 of dorsum of metasoma is dark to black, anterior 1/3 brownish with a darkened anteriormost part. The anterior 2/3 of meta-sternum is brownish and posterior 1/3 is dark. The wings and legs are similar to those of the female, but the

legs are slightly darker. The gaster is more rounded than in the female, shorter and not keel shaped.

***Euplectrus laphygmae* Ferriere (Eulophidae)**

These are small insects with the length of male ranging from 0.9 -1.2 mm and 1.2 - 1.6 mm for females. The size depended upon the number of individuals emerging from a host. Males and females are similar and generally black and lack metallic luster. The body shrivels or collapses when dried. Head lenticulate and, together with the mesosoma, longer than the gaster (metasoma) which is very short in both sexes (Plate 6.19). Gaster is about 3 times the length of head plus mesosoma. The mesosoma is black and gaster brownish or lighter. Female is bigger and generally darker than male. Both the male and female are very bristly with conspicuous long bristles on head and mesosoma.



**Plate 6.19: Male [x 44] and female [x 46]
*E. laphygmae***

The head of the female is black except the mouth parts area below the antennae (lower face) and genae which are yellowish (Plate 6.19). The area surrounding the eye is black. The entire head of the male, including the face is pale. The abdomen is coloured as in females but slightly paler. The antenna of the male is pale, eyes slightly reddish and smaller than in the female.

The antenna is inserted at the level of the eyes. The genae are conspicuously longer than the distance between the eye margin and vertex. Seven pairs of conspicuous bristles are present on the vertex and frons. The first pair at the base on the inner proximal part of eyes points inwards, the second pair between the lateral ocelli points inwards, the third pair at base of median ocelli point outwards. One pair at the base of distal part of eyes point outwards and the remaining three pairs on the frons, including a few smaller ones. At least eight pairs of conspicuous bristles on mesonotum and metanotum. The legs are relatively long compared with the body and are paler than the body.

The pronotum is short and has fine transverse carina at anterior margin. Mesonotum arched with different sculpture in middle and side, roughly reticulate in the middle, but more finely on the sides, and lacks carina. The scutellum has no longitudinal lines, rather fine sculpture and two pairs of setae. A conspicuous bristle is present at the base of the tegulae. The Sub-lateral lobe of the metanotum has a row of eight bristles.



Sub-marginal vein of forewing with five setae, with no interruption from marginal vein, distal end smoothly curved into parastigma. Stigmal vein long but shorter than post-marginal vein and ends in an uncus and stigma (Plate 6.20). A conspicuous seta on submarginal vein points inwards.

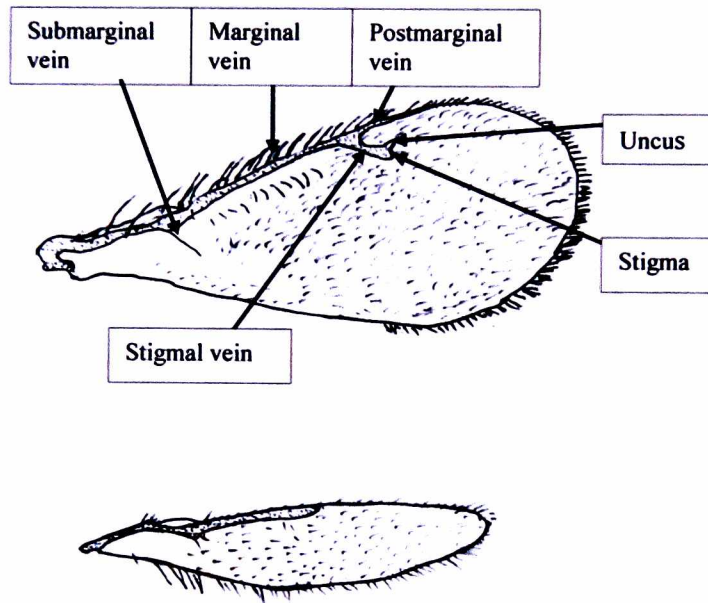


Plate 6.20: Schematic diagram of fore-wing and hind-wing of male *E. laphygmae* [x 30]

Hind tibiae with two spurs, one longer than the other. One spur is distinctly longer (Plate 6.21) than the basitarsus (basal tarsomere).

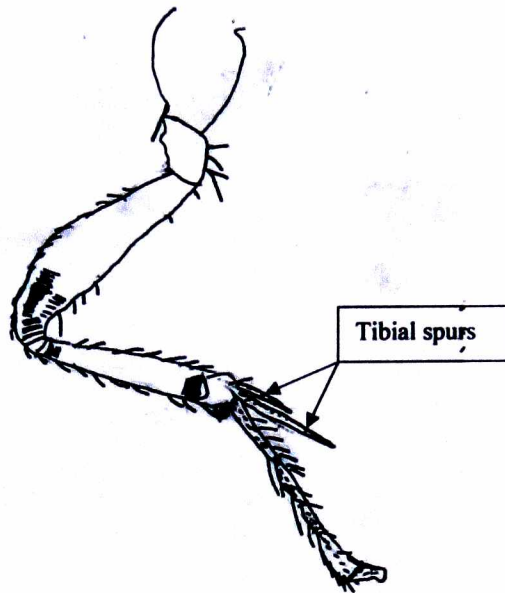


Plate 6.21: Schematic diagram of hind-leg of *E. laphygmae* [x 90]

The antenna of the female *E. laphygmae* is hairy, yellowish and seven segmented. A radicle is present and the flagellum is 5 segmented. Short inconspicuous anelli occur between all the antennal segments except between the basal flagellomere and the second and also between the fourth flagellomere and the club (Plate 6.22). The anelli are so inconspicuous they can be easily overlooked. The Scape is long and the pedicel is the narrowest segment. Club is apparently two segmented (slight depression laterally) and pointed at apex. Gaster with dark lateral sides, rest brownish yellow, ovipositor very short and inconspicuous.

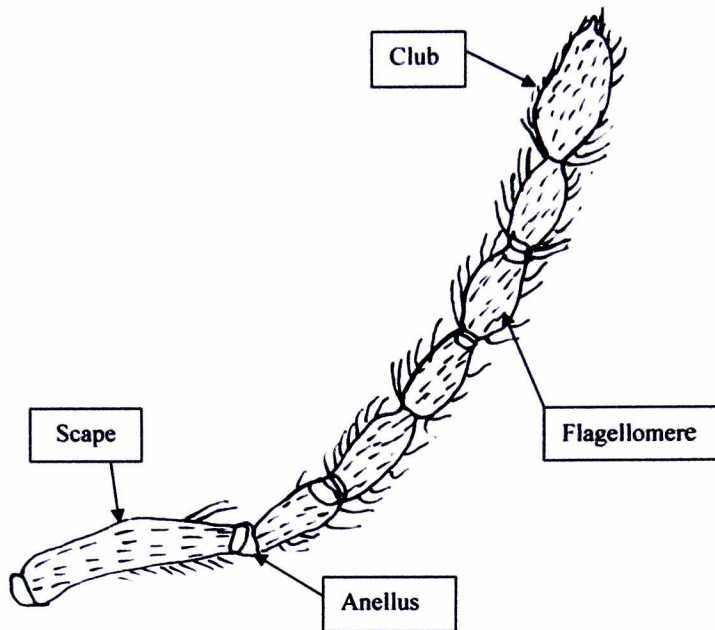


Plate 6.22: Schematic diagram of antenna of female *E. laphygmae* [x 100]

The antenna of the male *E. laphygmae* is also seven segmented with a conspicuous radicle (Plate 6.23). The flagellomeres except the basal one are shorter and more rounded than in the females. The Club has a very slight lateral depression.

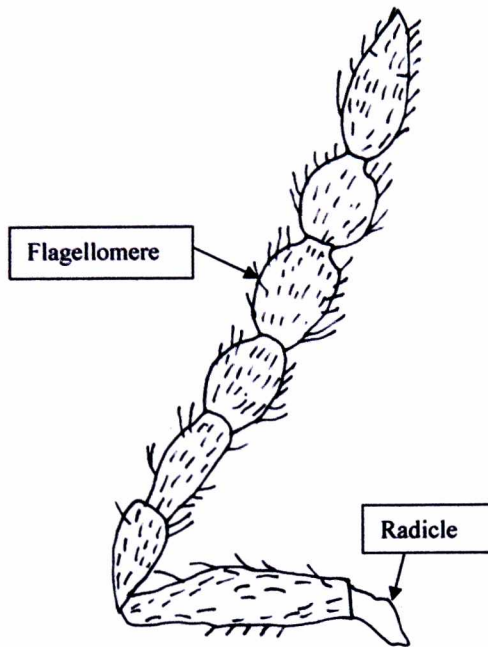


Plate 6.23: Schematic diagram of antenna of male *E. laphygmae* [x 100]

***Notanisomorphella* sp. (Eulophidae)**

This description is based on male specimens. This species appears generally black. The head and mesosoma are darker than the metasoma. The branched antennae are inserted quite close to the clypeus (Plate 6.24). The mesonotum with notauli incomplete. Scutellum without sub-lateral grooves, bare except for four setae. Wings long and wide, about two times as wide as long at the greatest width. Stigmal vein moderately long with conspicuous parastigma, post marginal vein distinct and longer than stigmal vein. Legs are similar in development. Proleg and midleg pale but hind

ones dark. Tibia straight, hind coxa with fine sculpture. Hind tibiae with posterior two-thirds of femur black, apices slightly pale, basal one-third pale, posterior half of tibiae dark. Petiole short, transverse, and not conspicuous (Plate 6.24). Gaster dorsally not highly sclerotised and collapsible especially lateral sides. Propodaeum with large reticulate median area and strong median carina (Plate 6.25).

This species was identified using the key by Boucek (1988) and confirmed by La Salle (CAB Bioscience British Museum Natural History, London). Boucek (1988) recognised two species groups (*proserpinensis* and *flaviventris*) based on the nature of the propodaeum. The specimen described here falls in the *flaviventris* group (propodaeum punctured-reticulate).

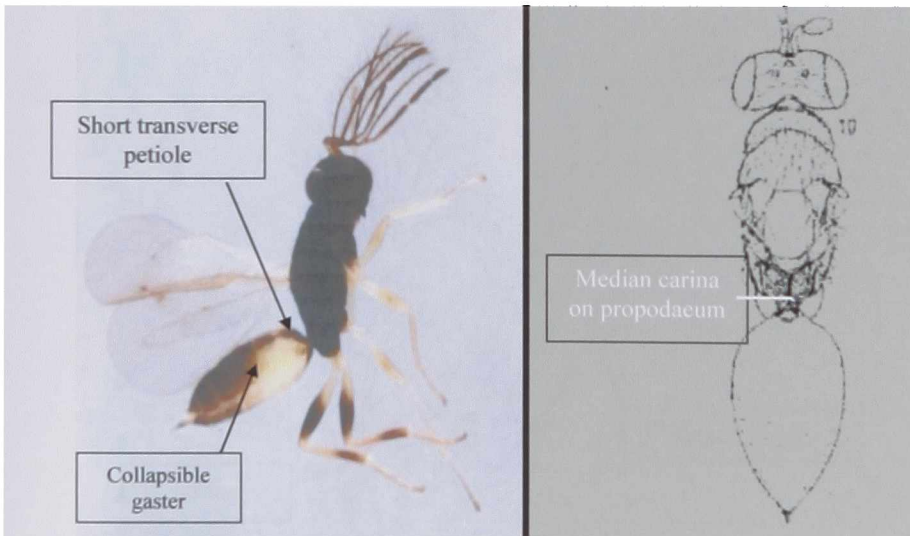


Plate 6.24: Male
Notanisomorphella sp. [x 21]

Plate 6.25: Propodaeum and
carina [x 29]
Source: Boucek, 1988

Antennae nine segmented and branched (Plate 6.24). The flagellum is seven segmented, brown and sparsely setose. Pedicel more or less rounded and shorter than basal flagellomere (Plate 6.26). Third flagellomere shortest of the flagellomeres. Pedicel plus four basal flagellomeres longer than fifth flagellomere. Fifth flagellomere almost as long as the two apical segments. Three long rami (branches) arise from the first two basal flagellomeres and fourth flagellomere (Plate 6.26). Rami appear to be somewhat jointed and bear conspicuous long setae which point upwards. First ramus arises from base of first flagellomere. The second arise sub-basally from second flagellomere, the third sub-basally from the fourth flagellomere

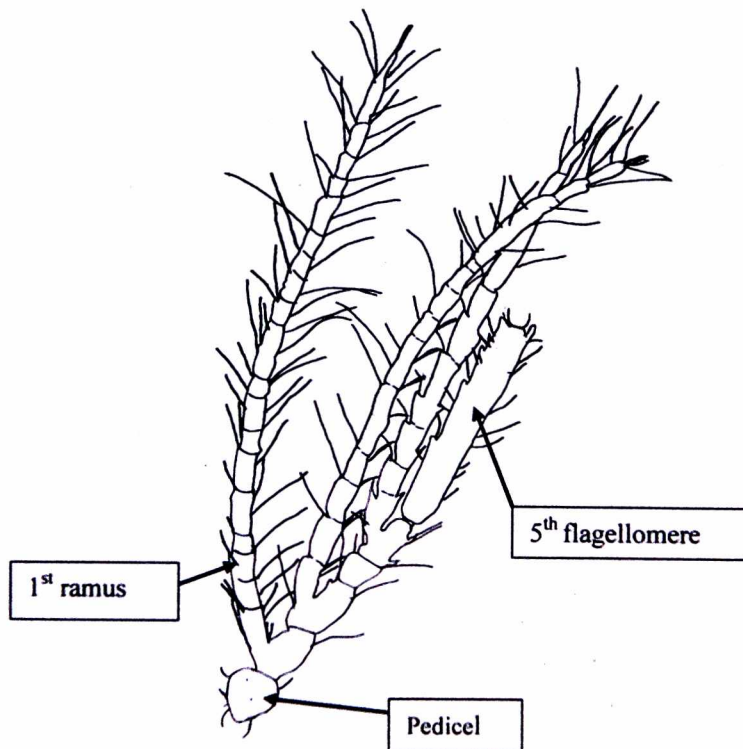
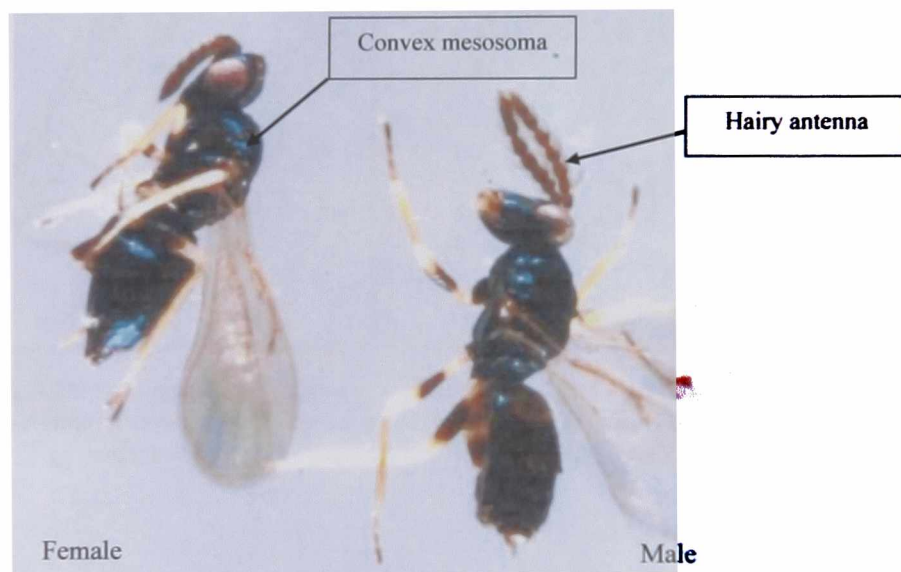


Plate 6.26: Schematic diagram of male antenna
Notanisomorphella sp. [x 90]

***Oomyzus sokolowskii* Kurdjumov (Eulophidae)**

This is a tiny ant-like (about 1mm long) metallic green species with a tinge of black. It is similar in appearance to *Tetrastichus atriclavus* s. l. recorded in this study. It is short with a convex mesosoma (Plate 6.27). Legs pale, middle portion of femur and coxae black. Fore and mid tibiae yellowish, hind tibiae pale. The tarsal segments are dark but not as black as coxa. Sub-median grooves on scutellum well developed and are close to each other. Male antenna is more hairy than in female.



**Plate 6.27: Female [x 50] and male [x 53]
*O. sokolowskii***

In females the antenna is stout, nine- segmented and brownish. A small annelus is present between the pedicel and the first flagellomere (Plate 6.28). Flagellomeres are almost quadrate. There is a three-segmented compact club which is shorter than the three funicle segments together. In males, the antenna is eleven segmented, longer than that of the female, and bears whorls of very conspicuous setae (Plate. 6.29). Segments beyond the pedicel have longer hairs on the lateral sides. Scape about three

times the length of pedicel. A small anellus is present between the pedicel and first flagellomere and between the latter and the second flagellomere. Club elongated and not compact and has a pointed tip. Club shorter than all funicle segments put together.

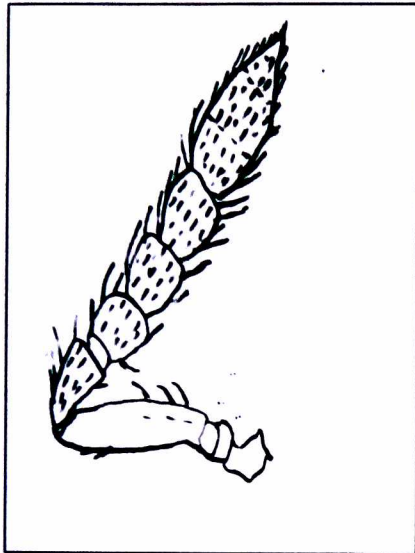


Plate 6.28: Schematic diagram of antenna of female [x 82] *O. sokolowskii*

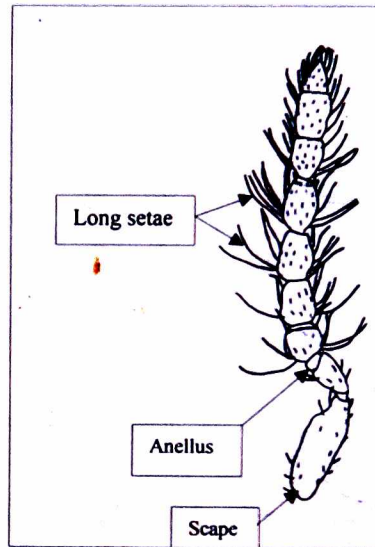


Plate 6.29: Schematic diagram of antenna of male [x 65] *O. sokolowskii*

Fore-wing with stigmal vein longer than postmarginal vein (Fig. 6.30). One bristle on submarginal vein. Forewing with a row of hairs along posterior half margin.

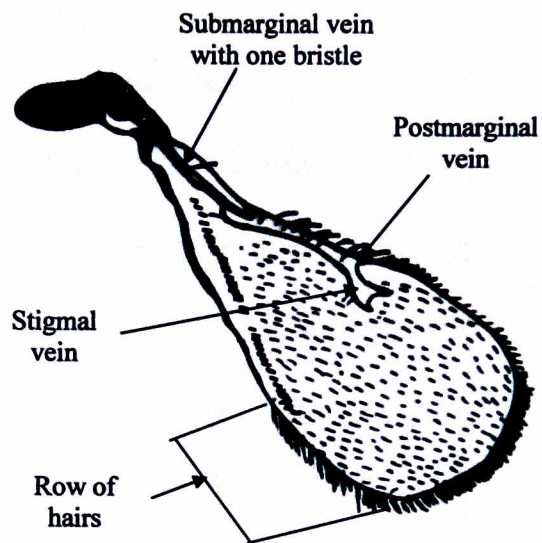


Plate 6.30: Schematic diagram of fore-wing of *O. sokolowskii* [x 40]

***Tetrastichus atriclavus* s. l. (Waterston) (Eulophidae)**

This species has a slight metallic bluish black sheen and has a narrower and longer abdomen (Plate 6.31) than *Oomyzus sokolowskii* described above in (Plate 6.27).



Plate 6.31: Female *Tetrastichus atriclavus* s.l. [x 68]

Striae present on face, scutellum with two notauli (longitudinal grooves) and an admarginal groove. Notauli is entire and linear. Forewing venation interrupted at base of parastigma. One bristle present on submarginal vein, post marginal vein absent. Propodaeum reticulate with an inverted 'Y' shaped carina. In females eyes are red and head looks rather stout and more or less rounded. Club and funicle darker than scape and pedicel. Females with three pairs of well developed setae on left side and two pairs on the right side of notauli. This species has a large black coxa and a femur which is black from the bases. Remaining parts of legs pale except tarsi with darkened apices. Scutellum with two grooves and setae on dorsal surface. Gaster of

female longer than head and mesosoma together. Thin ovipositor protrudes slightly beyond the abdomen.

Antenna is nine segmented with a three segmented compact club which appears like a single segment. There is a small ring-like anellus between pedicel and first flagellomere (Plate 6.32). In males antenna is black and also nine segmented.

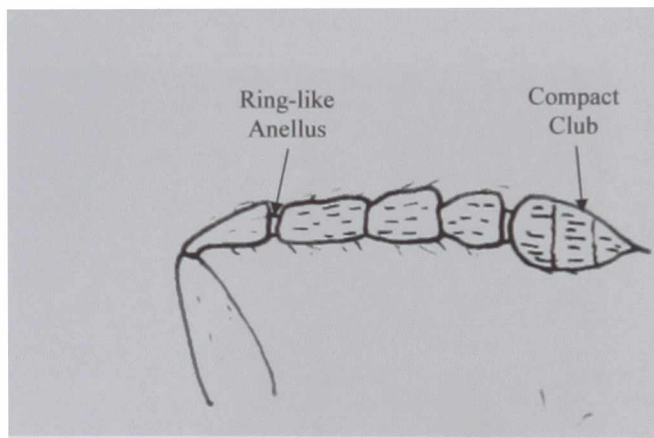


Plate 6.32: Schematic diagram of antenna of female *Tetrastichus atriclavus* s.l [x 80]

This species was identified as *T atriclavus* Waterston based on the presence of one dorsal bristle on the submarginal vein (Polaszek and La Salle 1995). The similar species *T. howardii* (Olliff) has two setae on the dorsal surface of the submarginal vein. *T. howardii* is mainly an Asiatic species but has been imported into Africa for investigation in biocontrol programmes (Kfir, 1991; Kfir *et al.*, 1993). It had, however, not been recorded in Ghana.

***Pediobius* sp. (Eulophidae)**

Both male and female of this parasitoid are small and similar in appearance. Body length is 1 - 2 mm long. They are metallic dark with a tinge of bluish green, especially on the mesosoma and metasoma (Plate 6.33). The entire body is strongly sclerotised and bristly. Female longer than male, length about two times that of male, elongate/ovate gaster with seven exposed segments, ovipositor short and stout. In male mesosoma is longer than metasoma, metasoma rounded, short and truncate (Plate 6.33).

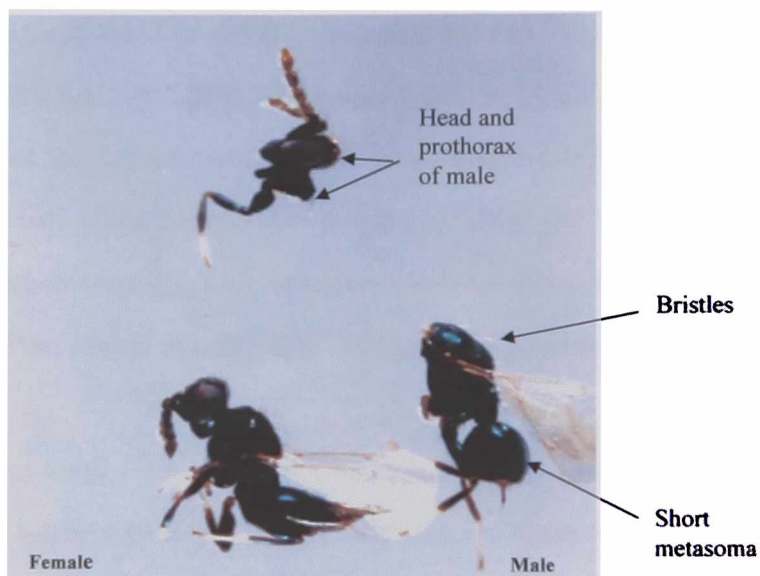


Plate 6.33: Female [x 29] and male [x 32] *Pediobius* sp.

The metasoma in males has pale bristles at apex, rest with sparse hairs. Only four segments visible on gaster, first tergite longer than the rest. Mesosoma and metasoma is more shiny in the male with a bluish green, terminal segments darker. Prominent petiole present, expanded at anterior and wider than long. The face and genae of both male and female are bright shiny green with a tinge of blue. Frontoververtex more or less rounded dorsally, reticulate dark and shiny with a tinge of bluish green. Genae in

facial view is straight and moderately long. Antennae inserted at about level of eye. Antenna of male is hairy, brownish and slightly longer than in female. Eyes are divergent (widely separated). Brownish bristles on vertex around ocellar area. Head wider than long. Mesosoma and metasoma of both male and female are strongly reticulate and with pale prominent setae, scutellum finely reticulate with setae on subscutellum. Pronotum short, with collar bearing a strong raised posterior margin like a carina. Anterior of pronotum of male dark reddish brown. A pair of spines on either side of pronotum. Femora and tibiae darker than antennae. Hind leg more developed than rest with tibial apical spine straight and dark. Coxae are large. From coxa up to tibia are dark reddish brown with a tinge of bluish green. Tarsomeres whitish except the last tarsomere; base of first tarsomere darkened. Forewings hyaline with pale brown background. Submarginal vein with two dorsal bristles; marginal vein prominent with a row of brownish spines, stigmal vein short with uncus and stigma. Postmarginal vein very short and faint and shorter than stigmal vein.

The antenna of females is six segmented, but club slightly divided into two on lateral sides. Scape bulges at the middle portion, longer than two times the length of pedicel. Pedicel is narrow at base. Three funicular segments with small anelli in between (Plate 6.34). First funicle segment longer than the 2nd and 3rd segments. Scape longer than club. Club with a conspicuous spine at apex. Second and third funicle segments and club with long hairs on sides, four on one side and three on the other side (Plate 6.34). First funicle segment and pedicel with hairs mainly on one lateral side.

The antenna in males is six segmented, the apical segment apparently divided into two, with the distal part ending in a spine-like process (Plate 6.35). The shortest

segment is the pedicel that is somewhat rounded but slightly narrower at base. A small anellus is present between scape and pedicel. The three basal flagellomeres are cylindrical but slightly bulges along the sides and are similar in size (Plate 6.35). The apical club plus the spine is about as long as the scape. In-between the flagellomeres there are inconspicuous ring-like anelli.

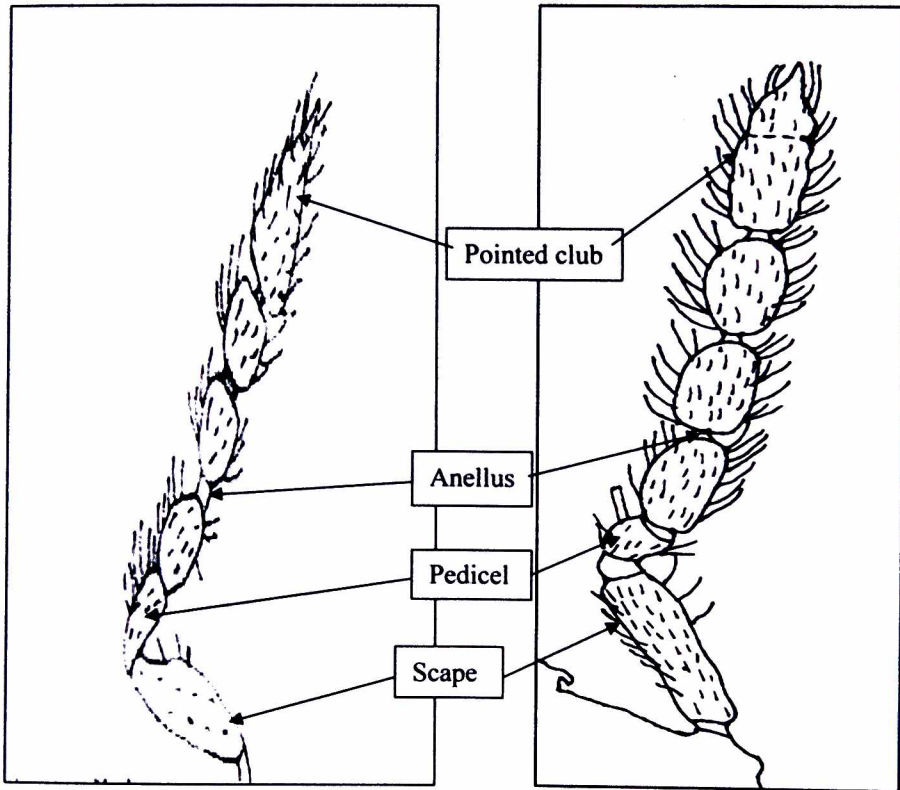


Plate 6.34: Schematic diagram of antenna of female *Pediosius* sp. [x 112]

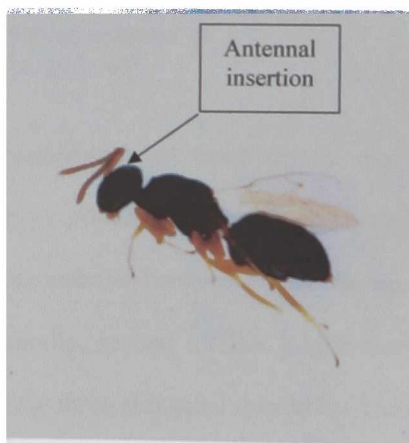
Plate 6.35: Schematic diagram of antenna of male *Pediosius* sp. [x 98]

***Trichomalopsis* sp. (Pteromalidae)**

The females and males are similar in appearance (Plates 6.36 and 6.37). They are blackish with a tinge of bluish-green, ant-like, and not very active. The length of the females range from 2.0 - 2.3 mm, and the males range from 1.7 - 2.0 mm. The antennal is insertion high above clypeus. Distance between point of antennal insertion and vertex is shorter than length of scape. Both sexes have geniculate antennae. The antennae of the female are dark brown except at the tip of the club which is slightly pale (Plate 6.36). Eyes are large and black. Head longer than wide from vertex. Occipital carina strong in postero-dorsal view. Mesosoma almost as long as metasoma and bulges on dorsal surface with a distinct pronotal carina. The legs are brownish but in males the coxae are blackish. The foreleg has a well developed sub apical spur which curves slightly towards apex. Midleg with straight sub-apical spur. Metasoma with clear segmentation. Ovipositor as thick as tibiae and protrudes slightly beyond metasoma. Wings are transparent with a light smoky appearance (Plates 6.36 and 6.37).



**Plate 6.36: Female [x 25]
Trichomalopsis sp.**



**Plate 6.37: Male [x 22]
Trichomalopsis sp.**



The antenna of the female is eleven segmented with a long scape (about two thirds the length of the rest of the antenna (Plate 6.38). The base of the pedicel is constricted. Two small anelli are present between the pedicel and first flagellomere. An anellus is present between flagellomeres 3, 4, 5, 6 and the basal segment of the club. Flagellomeres 3 - 6 are somewhat quadrate, 5 and 6 wider than long. Well developed stout club which is 3 segmented. The apical segment of the club is smaller than the other two.

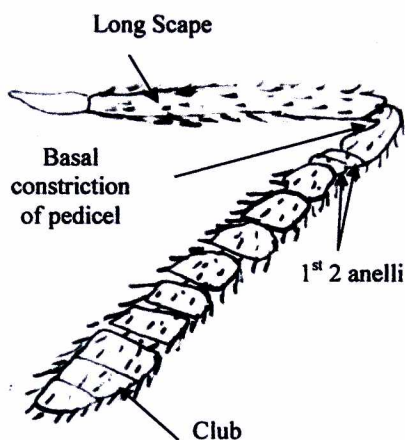
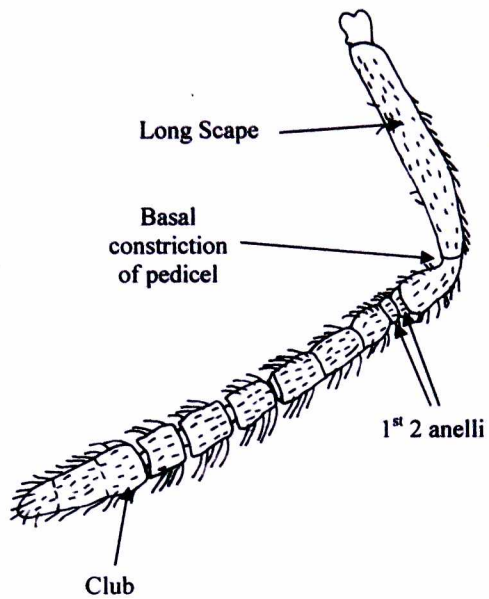


Plate 6.38 Schematic diagram of antenna of female *Trichomalopsis* sp. [x 67]

The antenna of the male is also eleven segmented but more slender than in the females (Plates 6.38 and 6.39). A radicle is present. There are two small anelli between the pedicel and the first flagellomere and also between third to the basal club segment. The first flagellomere bulges laterally, second to fifth longer than wide, sixth wider than long (Plate 6.39). The club is more elongated than in the female and not as distinctly segmented, middle segment longest.



**Plate 6 .39: Schematic diagram of antenna of male
Trichomalopsis sp. [x 72]**

The fore-wing is lightly setose. The submarginal vein is about twice as long as the marginal vein. The stigmal vein is well developed with a distinct stigma but shorter than post-marginal vein (Plate 6.40).

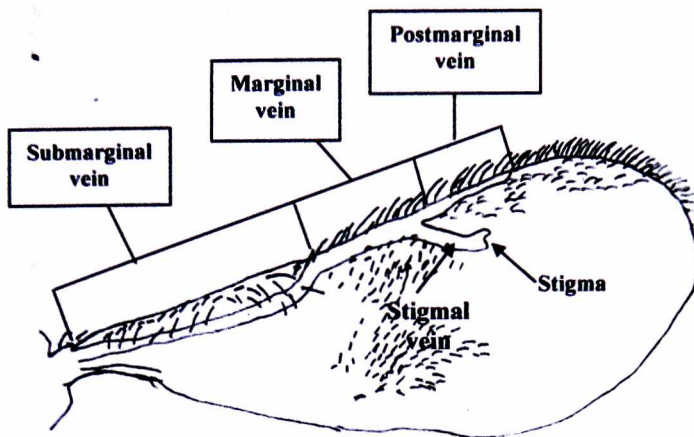


Plate 6.40: Schematic diagram of fore-wing of *Trichomalopsis* sp. [x 82]

6.3.2.3 Ceraphronoidea

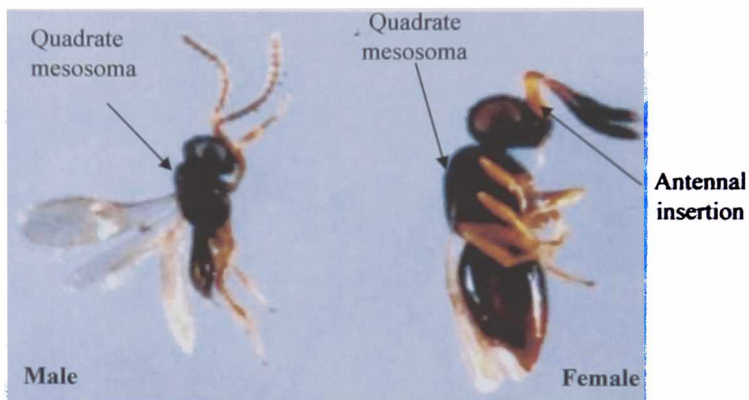
Aphanogmus reticulatus (Fouts) (Ceraphronidae)

This is a small dark brown to black parasitoid. The antennae arise below the eyes and immediately above the clypeus in both sexes. There is sexual dimorphism in the antennae and in body size (Plate 6.41). The male antenna is slender and more hairy than that of the female (Plates 6.41 and 6.42). The female is bigger and more robust than the male and its length range from 1.1-1.3 mm. Body length of male range from 0.9-1.2 mm. Legs of both sexes are light brownish. The wings are shiny and iridescent. Forewing with a narrow linear stigma. Mesosoma is quadrate in both sexes. Meso-tibia has one spur.

Female: Eyes are large and brownish. The antenna is geniculate and slightly curved towards the distal part. The Scape, pedicel and first flagellomere (first segment of flagellum) are brown; remaining segments brown to black (Plate 6.41). The apex of

the last antennal segment is paler. Mesosoma is darker than metasoma and both are stout. The metasoma is wide at the base and parts of the posterior end are brownish.

Male: Eyes are blackish or dark brown. The antenna is uniformly brown apart from the scape which is slightly pale.



**Plate 6.41: Male [x 25] and female [x 41]
*Aphanogmus reticulatus***



Plate 6.42: Male [x 40] *A. reticulatus*

The antenna of the male is moniliform and has eleven segments (Plate 6.43). Apart from the scape, the segments are generally similar in shape and have rounded apices. The club has a slightly constricted base. It is longer than the flagellomeres but shorter than the scape.

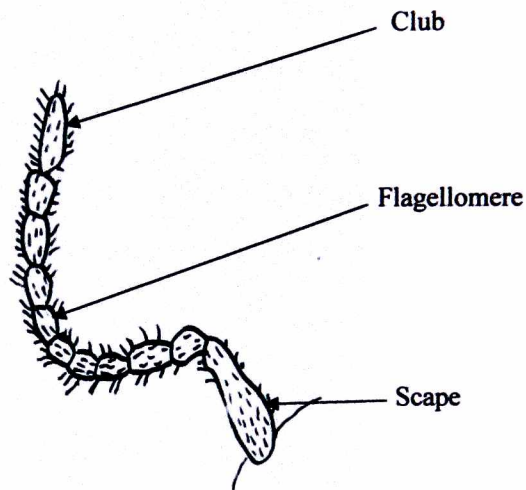


Plate 6.43: Schematic diagram of antenna of male *A. reticulatus* [x 96]

The antenna of the female is ten segmented (Fig. 6.44) and has short hairs on all segments. The scape is the longest segment with a constriction towards the base, giving it the appearance of a flask (Fig. 6.44). A small radicle is present. The pedicel is narrow and about half the length of the scape. The first five flagellomeres are the smallest and, together, are about two times (2x) the length of the last three apical segments. First flagellomere is the narrowest. The apices of the third to fifth flagellomeres are wider than their bases. The last three apical segments are widest in the middle and, together are longer than the scape. The last but one apical segment is evidently shorter than the club.

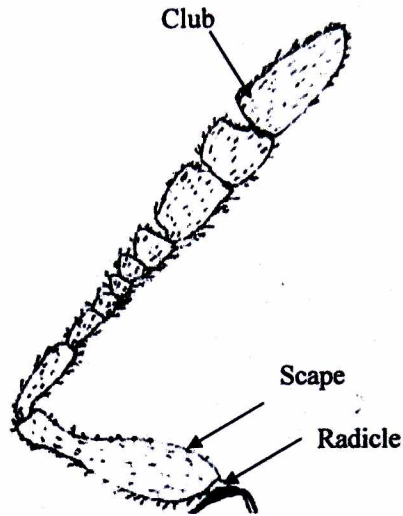


Plate 6.44: Schematic diagram of antenna of female *A. reticulatus* [x 90]

6.3.2.4 Muscoidea

***Blepharella vasta* (Karsh) (Tachinidae)**

This is a big metallic green and black fly with a total body length of 12mm. It has red eyes (Plate 6.45) and the anterior abdominal segments are brownish, and the posterior ones black and bristly.



Plate 6.45: *Blepharella* sp. near *vasta* [x 3.8]

***Peribaea orbata* (Wiedemann) (Tachinidae)**

These are small flies which are greyish black in appearance. They bear very stiff bristles (Plate 6.46) and have a superficial resemblance to the common housefly *Musca domestica*.



Plate 6.46: *Peribaea orbata* [x 15]

6.4 Discussion

The parasitoid species identified and described from the Lepidopteran pests on cabbage in this study is a contribution to our understanding and documentation of African entomo-fauna and the parasitic Hymenoptera in particular. It is also a significant contribution to research in biological based control of the Lepidopteran pests of cabbage especially, *P. xylostella* in Ghana. Out of the 15 species of parasitoids recorded, 7 were identified to the species level with 6 up to the generic level. Two were identified up to the species groups. Seven of the species: *Charops*

sp., *Brachymeria* sp., *Hockeria* sp., *Elasmus* sp., *Notanisomorphella* sp., *Tetrastichus atriclavus* S.L., *Pediobius* sp. and *Trichomalopsis* sp. have been recorded for the first time. The lengthy process of naming new species, which involves access to Type specimens and species, and all known species from other collections and museums has not enabled the species to be named in this study. Funds are being sourced to enable further studies to be carried out to name these species. Where possible, bar-coding (a new tool for identifying specimens) will be used as well as comparison with reference barcodes (Consortium for the Barcode of Life, 2009).

Apart from *C. plutellae*, all the other species are first records in Ghana. The identifications were either confirmed or determined at the British Museum of Natural History, United Kingdom and also the Systematic Laboratory of the United States Department of Agriculture, Gainesville in Florida. Some of the few existing descriptions and keys that were used were inadequate and as old as 90 years (Waterston, 1914; 1915 a & b; 1916; Ferriere, 1929; 1938; 1941). The fact that the specimens did not fit any of the species descriptions in the collections of the British Museum which holds the largest collection of Ghanaian specimens as well as from other parts of tropical Africa, the unavailability of keys for African species, and the inability of existing keys to key out the recorded species, support the proposal about the discovery of new species and buttress the importance of the information provided by the results of this study. Boucek (1988) observed that the minute size of the parasitic hymenoptera especially the Chalcidoidea makes their study unattractive. However, in Africa, the situation is particularly serious and acute due to lack of references on African entomo-fauna in general (Bio-Net INTERNATIONAL, 2006). Sometimes the problems encountered are due to inadequate descriptions without

illustrations and lack of access to Type materials (Boucek, 1988) or difficulty of identities of parasitoids (Waage and Greathead, 1986; Gupta, 1991; Smith *et al.*, 2008)

Cotesia plutellae (formerly *Apanteles plutellae*), a Microgastrine Braconid, was originally described in 1912 by Kurdjumov from *Plutella xylostella* (Fitton and Walker, 1992) and Wilkinson (1939) re-described it. Mason (1981) recognised several new genera in the subfamily with the result that many species previously in the genus *Apanteles* have new generic assignments. Despite this, some authors have not accepted the new classification and still use the old generic name *Apanteles sensu lato* resulting in confusion in the literature (Fitton and Walker, 1992) and the potential of introducing more misidentifications in the literature. This study has given detailed morphological descriptions including scanning electron micrographs of characteristics of males and females of *Cotesia plutellae* in Ghana. Rincon *et al.* (2004) observed important morphological and genetic differences between populations and between males and females of different populations from different geographic areas. The descriptions provided in this study of the Ghanaian populations on cabbage will hopefully, help reduce this problem in Ghana. It will also contribute to a better understanding of the biology of *Cotesia* species found on cabbage since the clarification of the identities of the different species is a key step in any biological study. The photographic descriptions and presentations can also be easily used as a guide in the field even by the non Taxonomist. The cosmopolitan species *C. ruficrus* (Haliday) occurs in parts of West Africa, but it is quite distinct from *C. plutellae*. It is also a gregarious parasitoid of internal and external hosts (Polaszek, *et al.*, 1994;

Walker, 1994), unlike *C. plutellae* which is solitary and does not parasitise internal hosts. The other species, *C. flavipes* is known to occur only in East Africa.

Species of *Charops* (Gupta and Maheshwary 1970; Maheshwary, 1971) have been recorded but none of these fit the description of the specimens recorded in the present study. Duodu and Lawson (1983) recorded *C. diversipes* Roman, in Ghana. However, other species previously recorded in Ghana were not available for comparison and other previous identifications were only up to the generic level.

The genus *Brachymeria* is relatively well known and most species are easy to recognize, based on the frequently yellow or white marked legs and tegulae. There are about 200 species worldwide and several are undescribed (Boucek, 1988). Keys to species have been provided for Europe, North America, India and the Oriental Region (Boucek, 1952; Burks, 1960; Narendra, 1989). Unfortunately, there are no keys to, or descriptions of African *Brachymeria*, making identification of species from this region difficult or even impossible (La Salle, CABI Bioscience U.K. pers. comm.). Boucek (1988) recorded *B. marmonti* (Girault) from Ghana

Waterston (1914), working on African Chalcidoidea described *Hockeria munda* sp nov. from Nyasaland, but the species observed in the present study is very different in body colouration, structure of wings, legs and antenna among others. The species on cabbage is similar to the Australian species *H. dioculata* (Girault) in having the post marginal vein very short. *Hockeria* Walker, 1834 is distributed in North America (5 spp), Europe (about 10 species), Asia (about 20 species), Australia (3 species, only 1 described) and in Africa at least 30 species but only 14 are described (Waterston,

1914; Boucek, 1988). The species described in the present study is a new record on cabbage in Ghana and may also be a new species to science.

Elasmus is the only genus generally recognised in the family Elasmidae though Riek (1967) established a second genus, based on differences in setal pattern of the meso-tibiae and meta-tibiae and relative length of sub-lateral scutellar seta. The family is sometimes classified as a subfamily of Eulophidae because of the structure of the protibial spur. Members are also similar to some Aphelinidae (Eriaporinae) in the structure of the meta-coxa, meta-notum and in wing venation (Goulet and Huber 1993). It is sometimes considered as a distinctive Chalcidoid family, principally because of its enormous flattened hind coxa (Burks, 1965). Burks (1967) classification is followed in this study. In addition, it is also distinguished by the 4-segmented tarsi, female with only 3 funicular segments, the male with 4 funicular segments of which the basal one has lateral branches. However, these are also Eulophid characters and some authors recognize it as a subfamily of Eulophidae. *Elasmus* is widely distributed in the old world tropics but about 260,000 nominal species occur. Keys for species are available for Europe, North America, Asia and Africa, India and Australia (Ferriere, 1929; 1947; Burks, 1965; Riek, 1967). The species recorded in this study could not be identified by the key for the African species prepared by (Ferriere, 1929). This key is out of date and the species described here is likely to be new to science.

Members of the genus *Euplectrus* Westwood can be easily distinguished by the lack of sub-lateral grooves on the scutellum and the presence of a transverse carina at the anterior margin of the pronotum (Boucek, 1988). However, Zhu and Huang (2003)

indicated that the pronotal carina is not constant in this genus and that it also occurs in another genus thus, cannot be a good generic character. Nevertheless, this character, the fore-wing characteristics and features of the head and its appendages in the male and female given in this study can be used to easily determine *E. laphygmae* in Ghana. Ferriere (1941) gave a description of this species in Africa but with no record from Ghana. Zhu and Huang (2003) studied the genus *Euplectrus* in China and also obtained loans of specimens from the British Museum, Japan, Hungary and other places, but they indicated that the head of males of *E. laphygmae* in China are mostly dark while those from elsewhere are entirely yellow as was found in this study. These authors also listed the distribution of this species in West Africa and other parts of Africa but did not include Ghana. The record in this study makes it the first in Ghana and also the first parasitising *Trichoplusia ni* on cabbage.

Aphanogmus reticulatus is widely distributed and known only in Africa (Polaszek and La Salle, 1995; Polaszek, 1997). *A. fijiensis* (Ferriere) had been recorded on stem borers in Ghana by Polaszek and La Salle (1995) but this is the first time *A. reticulatus* has been recorded and characterized on cabbage. Females of the two species can be separated by the following: Middle club segment of female antenna evidently shorter than first club segment and head broader in facial view in *A. reticulatus* than in *A. fijiensis*. Clypeus broadly truncate, medially with lateral extensions in *A. reticulatus*. In *A. fijiensis*, middle club segment equal to first club segment, head narrower in facial view and clypeus pointed medially without lateral extensions.

Notanisomorphella Girault has three synonyms; *Crateulophus* Masi, 1917; *Rauruna* Risbec, 1952; and *Sunha* Delucchi 1962 (Goulet and Huber 1993). The genus was synonymised under *Sympiesis* Forster by Girault (1917) and treated as such by subsequent authors (Boucek, 1988). This author, however, regarded it as a separate genus and distinguished *Notanisomorphella* by the presence of irregularly step-like but distinct plicae. This classification and distinction is used here. Boucek (1988) recognised two species groups (*proserpinensis* and *flaviventris*) based on the nature of the propodaeum. The specimen described here falls in the *flaviventris* group (propodaeum punctured-reticulate) and may also be a new un-described species.

Until 1957, *Oomyzus* was regarded as one of the synonyms of *Tetrastichus* sensu lato (Boucek, 1988). The current definition of this genus is given by Graham (1969 and 1987). The main features are: short black body with a distinct metallic tint, female flagellum stout, with funicular segments sub-quadrangle (almost as long as wide), the male flagellum with whorls of setae and propodaeum not short. Boucek (1988) noted that members often have weak sub-median grooves on the scutellum. The species recorded here *O. sokolowskii*, however, has a strong sub-median scutellar groove. The main difference between *O. sokolowskii* and *Tetrastichus atricalvus* s.l. also recorded in this study is that the antenna of the female of the latter species is paler, longer and not stout, eyes are bigger, body more elongated and streamlined. Other differences are in the colouration of legs, dorsum of metasoma more flattened and posterior end more elongated. Antenna of male *T. atricalvus* s.l. is also black and lacks the whorls of setae present in *O. sokolowskii*. Fore coxae are lighter in colour. However, some specimens varied in this last character.

Pediobius has been known for almost a century under the name *Pleurotropis* Foerster, 1856, and a large amount of literature is available under this name (Kerrick, 1973). However, in 1953, Ferriere established *Pediobius* Walker 1846 as the senior synonym (Burks, 1966; Kerrick, 1973). Waterston (1915) defined and characterised this genus and his views are still accepted. There are several keys to species of regional faunas: Europe (Boucek, 1965; Graham, 1969; Dawah, 1988); North America (Burks, 1966; Peck, 1985); tropical and subtropical Africa and Asia (Kamijo, 1986). Distribution of this species is worldwide with over 100 species, but Africa appears to be the centre of origin and contains the greatest number of species (Kerrick, 1973). Waterston (1915) and Masi (1940) cited in Boucek (1988) laid the basis for our knowledge of the African species. Kerrick (1973) determined species associated with the oil palm hispid *Coelaenomenodera elaeidis* Walker, for field entomologists in West Africa. He recorded and described eight species from Ghana but he indicated that a lot remains to be described.

Most species of *Trichomalopsis* are known from Holarctic and Oriental Regions (Graham, 1969). Species from rice paddies have been revised by Kamijo and Grissell (1982).

Blepharella sp. near *vasta* (Karsch) belongs to the family Tachinidae. This large genus badly needs revision and the specific name could not be determined for the specimens collected in the present study (Wyatt, NHM. United Kingdom, Pers. Comm.).

The parasitoids and hyperparasitoids recorded in this study are first records on cabbage in Ghana. Most of the existing descriptions are vague, and due to the paucity of information, lack of expertise and the out-of-date keys, some could not be identified to species level. No access could be obtained to examine type specimens. In addition, the species of parasitoids already recorded in Ghana were mainly from stem borers and most are of uncertain identity (Polaszek and La Salle, 1995).

CHAPTER SEVEN

7.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The dominant parasitoids and the major Lepidopteran pests on cabbage in Ghana have been identified. The parasitoid-host relations were; *C. plutellae* which parasitised *P. xylostella*, *T. ni*, *S. littoralis* and *H. undalis*, and *E. laphygmae* which parasitized *T. ni* and *S. littoralis*. *Cotesia plutellae* however, had a preference for *P. xylostella*.

There was seasonality in the occurrence and abundance of the pests. During the dry season (February - March) *P. xylostella* was the most abundant pest but, during the major rainy season (May - July), *T. ni* was more abundant. However, *P. xylostella* was the more important pest and occurred in significant numbers in all three seasons. The dry season was the worst time to grow cabbage due to the high incidence and infestation of *P. xylostella*. However, in areas where cabbage was grown for the first time under the Farmer Field Schools Programme in 1999 - 2001 and in some villages located near the Homasi concession of AngloGold, Ashanti Ghana Ltd. in the Amansie Central District in the Ashanti Region in 2008, *P. xylostella* was absent. *Trichoplusia ni* and *S. littoralis* may also be damaging to cabbage in the major and minor rainy seasons respectively as they occurred in abundance. Similarly, *Helicoverpa armigera* and *H. undalis*, even though, occurred in very small populations could be destructive due to the fact that they feed on the growing points of cabbage.

The most important parasitoid associated with the major pest was *Cotesia plutellae* which is a solitary endo-larval species and it occurred in all three seasons. *C.*

plutellae acted in a density dependent manner in relation to its hosts, thus, parasitism increased as host numbers increased. This should make it a good candidate in the development of an Integrated Pest Management Programme for control of its hosts on cabbage. However, this parasitoid appeared late in the season when pest populations had already built up. Hence in the dry season when high infestations of *P. xylostella* are expected this parasitoid may not be available in sufficient numbers to be effective. An intervention early in the season, possibly an augmentative release of *C. plutellae* at 25 days after transplanting could reduce pest numbers to counteract the effect of the initial time lag by this parasitoid.

Euplectrus laphygmae is a gregarious ecto-parasitoid species and occurred in the major and minor rainy seasons. Its specificity to mature larvae of *Trichoplusia ni* and *S. littoralis* undoubtedly makes it also a parasitoid that must be considered in the development of any management strategy of these pests on cabbage.

Oomyzus sokolowskii and *Trichomalopsis* sp. are also important parasitoids/ hyperparasitoids of *P. xylostella* on cabbage in Ghana. The six species of parasitoids (*Blepharella vasta*, *Peribaea orbata*, *Chelonus curvimaculatus*, *Euplectrus laphygmae*, *Charops* sp. and *Notanisomorphella* sp.) recorded from *S. littoralis* caused insignificant amount of parasitism and may not be important mortality factors for this species.

The total contribution of all the parasitoid species however, could be significant in keeping the cabbage pest populations down.

No egg parasitoids were observed in this study. Eight of the Hymenoptera parasitoid species recorded in the following genera: *Charops*, *Elasmus*, *Hockeria*, *Brachymeria*, *Pediobius*, *Tetrastichus*, *Notanisomorphella*, and *Trichomalopsis* in this study, are first records on cabbage in Ghana and likely to be new species.

Cotesia plutellae undoubtedly, play an important role in the natural and biological control of *P. xylostella* and *T. ni*, but indiscriminate use of insecticides could reduce their effectiveness. The pyrethroid, Karate (a common insecticide used by Ghanaian farmers) was directly and highly toxic to *C. plutellae* as it caused 100% mortality in the adults within ten seconds of direct exposure. Karate also caused indirect toxicity as it killed the adults in the process of eclosion or reduced their longevity. It could therefore, reduce the effectiveness of *C. plutellae* by eliminating them, reducing their fecundity and fitness or causing a decrease in the numbers that will be available to sustain succeeding generations of the parasitoids. This adverse effect on such an important parasitoid has severe implications on the continued use of Karate by Ghanaian farmers. These results suggest that in the development of an Integrated Pest Management (IPM) programme that will include the use of *C. plutellae*, Karate should not be included. *Bacillus thuringiensis* may be a better alternative as it caused less mortality to the adult parasitoid. Lower concentrations of neem seed extracts could be investigated in a biological based control programme of pests on cabbage, as Neem seed water extract at 50 g/l and Neemazal at 1.0 ml/l adversely affected metamorphosis in *C. plutellae*.

The present study has for the first time, generated new and useful information on the identity, description, biology, illustrations, seasonal occurrence and distribution, of

the important parasitoids and their hosts on cabbage in Ghana. It has also provided new evidence on the toxicity of the commonly used insecticide (Karate), and neem products at certain concentrations to the most important parasitoid of the major pest, *P. xylostella*. The practical relevance of this information to producers is the application of this knowledge in the correct timing of planting for sustainable production and reduction in insecticide use and thereby, reduce costs and protect the major parasitoids and health of consumers of cabbage in Ghana.

The results of this study are significant to African entomo-fauna in general and on cabbage in Ghana in particular. Even though the identification and descriptions of the parasitoids have been worked out in this study, it was a daunting task due to lack of previous research and expertise in this area, the unavailability and out-of-date literature on African Hymenoptera, especially Ghanaian species.

7.2 Recommendations

From the results of the present study, the following recommendations are made:

- 1) Further studies involving the examination of type species and other collections are needed to confirm the status of the proposed new species of parasitoids observed in this study.
- 2) Even though, egg parasitoids were not found in this study, species of *Trichogramma* have been recorded as egg parasitoids in some other places outside Ghana. This is an area that requires further investigation in Ghana.
- 3) The high rates of parasitism by *C. plutellae* of its hosts on Karate treated plots, as well as the longevity and competitiveness of adults of the parasitoid

emerging from pupae exposed to the insecticide, are worth investigating and also determining the insecticide resistance status of the parasitoid.

- 4) There is the need for studies to determine the most appropriate times and method of application of *B. thuringiensis* in an IPM programme on cabbage in Ghana. Lower doses of neem should be investigated to determine the appropriate rates in order to conserve the dominant parasitoid, *C. plutellae*.
- 5) It is advocated that more surveys and research on the parasitoids should be carried out to facilitate documentation of the local fauna and to reduce reliance on the use of pesticides.
- 6) Production of Field guides of the parasitoids and their hosts on cabbage would greatly contribute to the usefulness of the results of this study. Documentation of the fauna is what all decisions regarding conservation and exploitation of biological resources depend on.

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APPENDICES

APPENDIX 3.1

Towns where cabbage was grown for the first time in 1999-2001 or 2008

Region/Town(s)	<i>P. cheiranthi</i>	<i>H. undalis</i>
<u>GREATER ACCRA</u>		
Dodowa	-	+
Moyose	+	-
<u>EASTERN</u>		
Donkorkrom	-	+
Amankwa Tano	+	-
<u>WESTERN</u>		
Suiano	+	-
Denche/Moasue	+	-
Senyaguakrom	+	-
<u>*ASHANTI</u>		
Prago	-	+

**Cabbage grown for first time in 2008*

+ Means present

- Means not present

APPENDIX 3.2

Total Numbers of *C. plutellae* pupae collected from the different plots exposed to insecticides in the field.

Treatment	Major rainy season	Dry season
	Total no. of pupae	Total no. of pupae
Unsprayed	194	178
<i>Bt</i>	94	160
Karate	518	828
NSWE	-	177
Total	806	1343

APPENDIX 3.3

Percentage emergence of *C. plutellae* adults collected as pupae exposed to different insecticides in the field

Species	Major rainy season (N=865)	Dry season (N=1302)
<i>C. plutellae</i>	84.0	95.2
<i>A. reticulatus</i>	6.35	-
<i>Trichomalopsis</i> sp	8.20	4.1
Others	1.41	0.7